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Original Communications

LOBAR OBSTRUCTIVE EMPHYSEMA IN INFANCY TREATED BY LOBECTOMY

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LOCALIZED emphysema is commonplace in the presence of pulmonary infection¹⁻³ or an intrabronchial foreign body,^{4,5} but rarely has it been described in otherwise apparently normal infants. Lobar obstructive emphysema in infancy produced by an abnormality of the bronchus is being recognized with increasing frequency. The recent publication of several reports of successful lobectomy for obstructive emphysema in infants has made the recognition and treatment of this condition of greater interest to surgeons.

In 1939 Overstreet⁶ reported the case of an infant with obstructive emphysema of the left upper lobe who was found to have deficient cartilage rings in the left upper lobe bronchus on post-mortem examination. Overstreet mentioned that a lobectomy had been performed in another hospital for a similar lesion in an infant without relief of symptoms. Other scattered descriptions of obstructive emphysema in infancy resulting from a bronchial abnormality appeared but on none of the patients was an operation performed.^{9, 10}

Gross and Lewis,¹¹ in 1945, presented a case involving an infant with obstructive emphysema of the right upper lobe resulting from the absence of cartilage rings in the right upper lobe bronchus. This was associated with a pleural defect of the anterior mediastinum. Lobectomy was performed and the mediastinal defect repaired. Lewis and Potts¹² later added a similar case of an infant with an anterior mediastinal defect associated with emphysema of the right middle lobe. No bronchial abnormality was found. Lobectomy was performed but the mediastinal defect was not repaired. Leahy and Butsch¹³ also were able to report a successful lobectomy for emphysema of the left upper lobe in an infant.

The first presentation of a series of infants with lobar obstructive emphysema believed to be on a congenital basis appeared in 1951 when Robertson and

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Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 30, 1953.

James¹⁴ reported the cases of five infants with this condition. Three of the infants underwent lobectomies. Robertson and James believed that the obstructive emphysema present in these infants was due to a check valve mechanism in the bronchus of the involved lobe. In two of the patients the bronchial obstruction was thought to be produced by weakness of the bronchial wall or a flap of bronchial mucosa. However, in another infant pressure on the bronchus from an abnormal, dilated vein was felt to contribute to the obstruction. In two of the infants no abnormality of the bronchus was found.

Shaw¹⁵ stated that abnormal flaccidity of the bronchus was responsible for the bronchial obstruction present in the two patients with obstructive emphysema upon whom he operated. In one of the patients a single segment was involved. In the other the entire lobe was emphysematous. Williams¹⁶ has reported the case of an infant with emphysema of the right middle lobe. Lobectomy was performed but no bronchial abnormality was described.

Finally, Fischer, Potts and Holinger,¹⁷ in 1952, presented five additional cases of infants with lobar obstructive emphysema for which lobectomy had been done. In two of the infants, in whom the left upper lobe was involved, the bronchial obstruction was believed to be related to pressure on the left bronchial tree by the ductus arteriosus. In one infant there was hypoplasia of the bronchial cartilages of the involved lobe. No definite bronchial obstruction was found in the other two infants. These authors first pointed out that in none of the cases reported by them or by other authors had a lower lobe been involved. They speculated that greater expiratory forces acting on the lower lobes prevented the trapping of air in them.

In the majority of the patients respiratory distress was noted soon after birth. The infants had wheezing respirations, dyspnea, and cyanosis. The onset of illness was rarely associated with definite evidence of respiratory infection. The infants did not improve materially with any therapy. They usually had increasing respiratory distress. It was necessary to operate upon some of the infants as emergencies. Lobectomy in these patients was lifesaving. All of the patients operated upon survived the operation and all were greatly improved with one exception. None of the infants was reported to have had further respiratory difficulty following operation with the exception of the patient mentioned by Overstreet. The diagnosis of obstructive emphysema unrelated to infection or to an intrabronchial foreign body was not difficult once the clinical and roentgenographic picture had been recognized. However, this form of obstructive emphysema was confused frequently with cystic disease of the involved lobe, pneumonia, or atelectasis of adjacent lobes.

The first infant in whom lobar obstructive emphysema was recognized in the University Hospital was admitted in May, 1950. Within a space of two years three additional infants with this condition were admitted. These infants presented the same clinical and roentgenographic features described by previous authors. In contrast to the experience of others, they continued to have respiratory symptoms following discharge from the hospital, although they were improved by lobectomy.

CASE REPORTS

CASE 1.—

History.—R. B., U. H. No. 682439, a 7-month-old white male infant, was admitted to the Pediatric Service of the University Hospital on May 23, 1950, with difficulty in breathing. The infant was born Nov. 7, 1949, following an uncomplicated pregnancy of eight months. He weighed 6 pounds, 6 ounces at birth. The infant breathed and cried spontaneously.

Soon after birth it was noted that he had some difficulty in breathing. Oxygen was not required and the infant nursed well. When he was three weeks old he developed wheezing and a dry cough which was aggravated by crying. The cough bore no relation to meals and occurred both day and night. Fever was not noted by the parents. The administration of penicillin and a sulfonamide made little change in the condition. The symptoms subsided somewhat from the seventh to the tenth week of age but recurred again with increasing severity. The administration of penicillin on several other occasions produced no change in the symptoms.

The infant continued to do poorly. Despite a good appetite, he gained weight slowly. Cyanosis was noted when he cried.

Family History.—Two older brothers, three years and sixteen months of age, were normal. There was no family history of congenital abnormalities or of allergy.

Physical Examination.—Temperature was 101° F. (rectally); blood pressure, 104/45; pulse, 130; respirations, 28; weight, 11 pounds, 13 ounces.

On examination the infant was inactive and underdeveloped. He cried weakly and was cyanotic when he cried. Respirations were slightly labored and expirations were prolonged. There was retraction of the thoracic cage during inspiration. The anterior-posterior diameter of the chest was increased. The right hemithorax was more prominent than the left. Breath sounds were decreased over the right hemithorax. A few coarse râles were heard at the right apex. The mediastinum was shifted to the left. The heart was normal. No other abnormalities were found.

Laboratory Data.—Kahn test was negative; hemoglobin, 11.2 Gm.; red blood cells, 4.64 million; white blood cells, 13,750 with 39 per cent polymorphonuclear leukocytes, 47 per cent lymphocytes, and 12 per cent monocytes; urine, normal findings; tuberculin, negative 1/1000; normal trypsin activity.

Roentgenograms.—Seven films of the chest exposed at another hospital from Dec. 5, 1949, through April 18, 1950, were all interpreted as showing emphysema of the right mid-lung field with a well-defined triangular area of increased density at the right base and patchy density in the right upper lung field. The left lung was normal. The mediastinum was shifted to the left. Chest films taken at the time of admission showed similar changes (Fig. 1). The infant was fluoroscoped. There was no mediastinal swing with respiration and no change in heart size.

Course.—It was felt that the infant had pneumonitis or atelectasis of the right upper lobe and the right lower lobe, although there was no fever. On one occasion an audible expiratory wheeze was noted. Excellent temporary relief was obtained with Adrenalin. The patient continued to have periodic respiratory distress which increased in frequency and duration. X-ray films of the chest demonstrated increase in the emphysema of the right mid-lung field and greater shift of the mediastinum to the left. It was at last realized that the infant's problem was one of obstructive emphysema rather than atelectasis or pneumonitis.

Bronchoscopy.—On June 19, 1950, he was anesthetized with ether and the bronchial tree examined through the 3.5 mm. bronchoscope. There was some edema and hyperemia of the entire bronchial tree. The bronchial walls approximated during expiration. No foreign body was found. No localized obstruction of the bronchial tree was noted.

Operation.—On June 29, 1950, a right thoracotomy was performed through the fourth intercostal space. Ether-oxygen anesthesia was administered through an endotracheal tube. When the chest was opened a tense, distended mass of lung presented. This filled the whole right hemithorax. It could not be compressed. The mass was delivered into the wound. The infant's somewhat precarious condition immediately improved. The compressed right upper lobe and right lower lobe now could be inflated easily by the anesthetist. There were no enlarged lymph nodes about the right middle lobe bronchus. No bronchial abnormality was noted. A right middle lobectomy was carried out easily by the individual ligation technique. The expanded right upper lobe and right lower lobe filled the chest. Anterior and posterior drainage tubes were inserted. The chest wall was closed in layers with silk. Blood loss was estimated to be 142 c.c. The infant was given 200 c.c. of whole blood during the operation. He was returned to the ward in excellent condition.

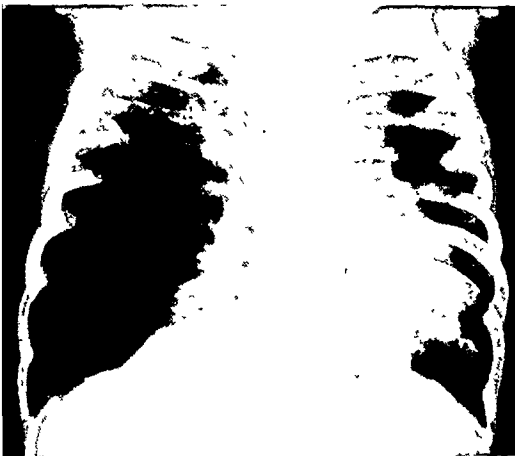


Fig. 1.



Fig. 2.

Fig. 1 (Case 1).—Preoperation roentgenogram exposed May 24, 1950. There is marked emphysema of the right middle lobe with compression of the right upper lobe and right lower lobe. The mediastinum is shifted to the left, and the right hemidiaphragm depressed.

Fig. 2 (Case 1).—Postoperation roentgenogram exposed Jan. 9, 1953. There is no emphysema. A small residual area of pleural reaction persists in the right paratracheal region.

Examination of the Specimen.—On gross examination there was uniform emphysema of the entire middle lobe (Fig. 3). The bronchus, although small in comparison with the greatly distended lobe, was not abnormal. Cartilage rings were present in the bronchial wall. On microscopic examination there was marked emphysema of the pulmonary parenchyma and dilatation of the smaller bronchi (Fig. 4). Slight, chronic bronchitis was present in isolated bronchi. No abnormality of the middle lobe bronchus was found in sections taken through it. Elastic tissue stains showed normal amounts of elastic tissue to be present.

Postoperative Course.—The infant's symptoms were completely relieved following operation. He became much more bright and active. The right upper lobe and right lower lobe expanded well and filled the right hemithorax, although the mediastinum was shifted slightly to the right. He was discharged on July 10, 1950. At this time respirations were normal.

Course Following Discharge.—The infant remained improved and developed in a normal manner. However, he had continued respiratory difficulties. On three occasions admission was necessary for dyspnea and wheezing respirations during an apparent acute respiratory infection. These symptoms responded to antibiotic therapy. In addition, the infant had frequent, milder episodes during which similar symptoms were present.

Bronchoscopy was repeated on Oct. 25, 1950. Again it was noted that the bronchi collapsed during expiration.

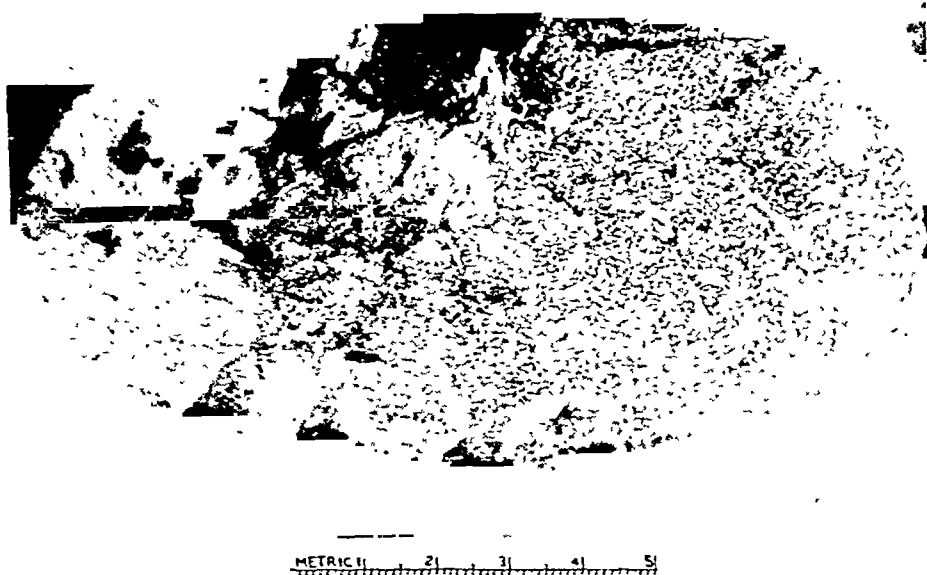


Fig. 3 (Case 1).—Photograph of the cut surface of the right middle lobe. There is marked emphysema of the entire lobe.

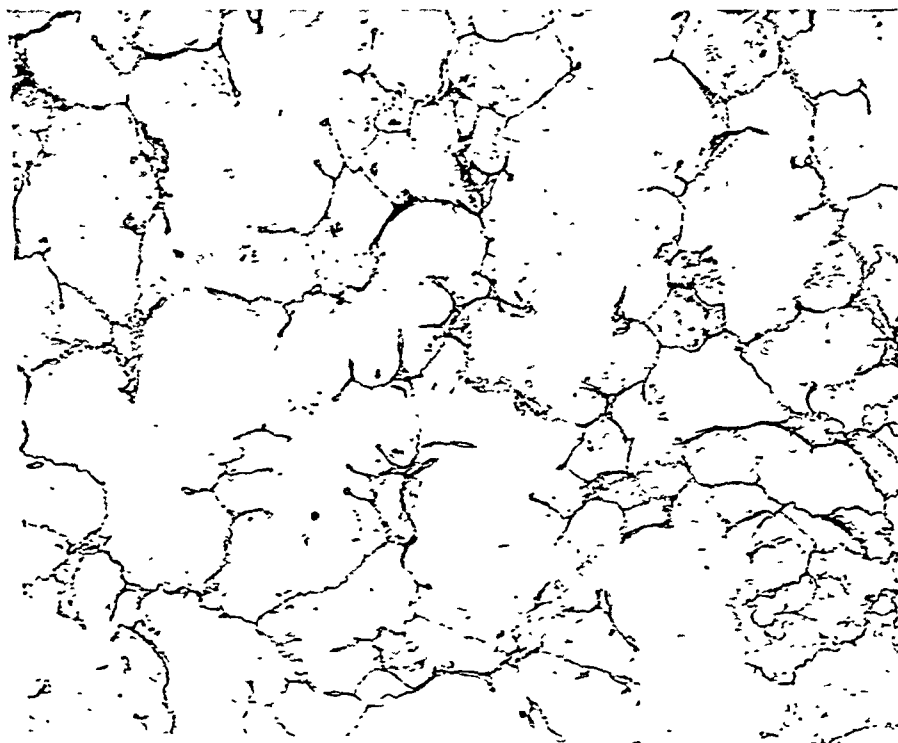


Fig. 4. (Case 1).—Photomicrograph of a section of the right middle lobe. Marked emphysema is present. There is no evidence of infection ($\times 75$).

X-ray views of the chest showed a triangular shadow of increased density in the right paratracheal area. This cleared gradually and was thought to represent reaction to operation rather than atelectasis.

The patient was last admitted Feb. 1, 1953. Admission was necessary for wheezing, coughing and difficult respiration. Adrenalin on one occasion gave temporary relief. The child quickly responded to penicillin and sulfadiazine. Because the symptoms resembled asthma, sensitivity studies were carried out but no specific protein sensitivity was found.

The infant was fluoroscoped and chest films were obtained Feb. 3, 1953. The diaphragms moved well. There appeared to be slight emphysema of the lung fields bilaterally but no unusual flattening of the diaphragms. There was no mediastinal shift with respiration. No emphysema had been seen in chest films obtained Jan. 9, 1953 (Fig. 2), and the findings at the time of admission may have been associated with the acute episode described.

CASE 2.—

History.—A. C., U. H. No. 712813, a white male infant 6 days old, was admitted to the Pediatric Service of the University Hospital Sept. 14, 1951, with difficulty in breathing and cyanosis. The mother's pregnancy was normal and the infant was delivered after an uncomplicated five-hour labor on Sept. 8, 1951. The infant weighed 6 pounds, 13 ounces. He breathed spontaneously and seemed normal.

During the first two post-partum days the infant had no respiratory difficulty. On the third day, when the mother's milk started to increase in amount, the infant choked on a feeding. On the fifth post-partum day the infant was returned to the nursery after a feeding. He then became cyanotic and appeared to have obstructed respiration. The infant coughed up thick material which had the appearance of ingested milk and the condition improved. However, he continued to have rapid, labored respirations.

Family History.—A sibling, 3 years of age, was normal. The father gave a history of seasonal allergic episodes in which he had moderately severe asthma. There was no family history of congenital abnormalities.

Physical Examination.—Temperature was 99.4° F. (rectally); pulse, 140; respirations, 80 to 100.

The infant was active but was cyanotic. He was breathing rapidly and vigorously. Examination of the thorax showed active diaphragmatic and intercostal movements. The accessory muscles of respiration were being employed. Breath sounds were greatly diminished and resonance to percussion was increased over the left hemithorax. The mediastinum was shifted to the right. There were a few scattered râles heard over the right upper chest posteriorly. The remainder of the physical examination showed only normal findings.

Laboratory Data.—Kahn test was negative; hemoglobin, 15.8 Gm.; white blood cells, 22,500 with 44 per cent polymorphonuclear leukocytes, 46 per cent lymphocytes, 5 per cent monocytes, and 5 per cent eosinophils; urine, normal findings.

Roentgenograms.—Chest films exposed at another hospital on the day of admission showed increased radiolucency of the left hemithorax with shift of the mediastinum to the right. Examination at the University Hospital confirmed these observations (Fig. 5). In addition, the left hemidiaphragm was noted to be depressed. On fluoroscopy there was decreased motion of the depressed left hemidiaphragm. No shift of the mediastinum with respiration was noted. Twelve hours after admission additional films of the chest were exposed. There was a further increase in the radiolucency of the left hemithorax with additional shift of the mediastinum to the right. It was felt that the infant had obstructive emphysema of the left upper lobe.

Course.—During the day of admission the infant's respiratory distress increased in severity. With the confirmation by chest films of increasing emphysema of the left upper lobe it was felt that lobectomy should be performed as an emergency.

Operation.—The infant was anesthetized with ether-oxygen in a closed system. An endotracheal tube was not employed. A left thoracotomy was performed and the chest was entered through the fourth intercostal space. Inspection showed a firm, pale mass of distended lung which filled the entire pleural cavity. This could not be deflated by compression. With some difficulty the mass was delivered into the wound and was found to be the left upper lobe. The small, compressed left lower lobe could then be inflated easily by the anesthetist. The infant's condition immediately improved.

A left upper lobectomy was easily performed by the individual ligation technique. The left upper lobe bronchus was not grossly abnormal, although it could be compressed very easily. There were no enlarged lymph nodes about the bronchus. No external source of compression was found. The left lower lobe filled the pleural cavity well.

Anterior and posterior drainage tubes were inserted. The chest was closed in layers with fine silk. Blood loss was 96 c.c. The infant received 100 c.c. of whole blood during the operation. He was returned to the ward in excellent condition.

Examination of the Specimen.—No gross obstruction of the left upper lobe bronchus was found. Cartilage rings were present in the bronchial wall. There was uniform, marked emphysema of the entire lobe. On microscopic examination there was marked emphysema with dilatation of the small bronchi and bronchioles. No evidence of infection was found. Elastic tissue stains demonstrated a normal amount of elastic tissue to be present.

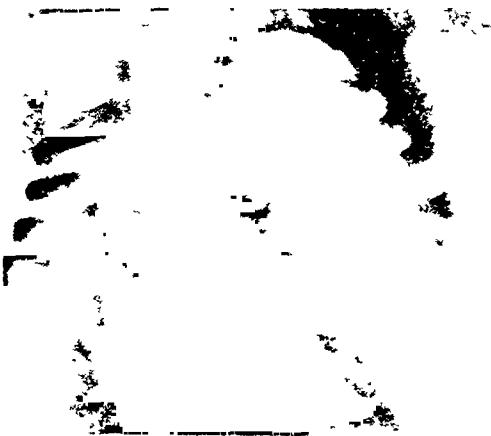


Fig. 5.

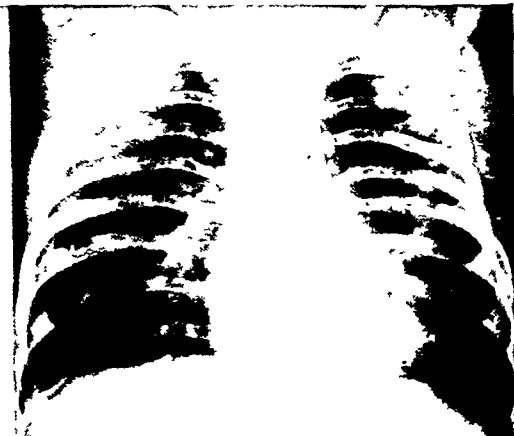


Fig. 6.

Fig. 5 (Case 2).—Preoperation roentgenogram exposed Sept. 14, 1951. There is emphysema of the left upper lobe with depression of the left hemidiaphragm and shift of the mediastinum to the right.

Fig. 6 (Case 2).—Postoperation roentgenogram exposed Feb. 9, 1953. Localized emphysema is present at the left base.

Postoperative Course.—The infant's recovery from the operation was dramatic. He had no further respiratory symptoms. The left lower lobe expanded and filled the left hemithorax. There was slight shift of the mediastinum to the left. The infant ate well and gained weight rapidly. He was discharged Sept. 25, 1951.

Course Following Discharge.—He was well for three months. At that time he began to have attacks of wheezing respirations associated with marked activity. He developed repeated upper respiratory infections usually accompanied by wheezing. On several occasions penicillin seemed to produce relief. The infant was readmitted to the University Hospital in March, 1952. At this time he had wheezing, cough, and moderate dyspnea. He was thought to have infectious tracheobronchitis. He quickly responded to antibiotics, steam inhalations,

and ephedrine and was discharged. However, despite normal growth and weight gain, he continued to have episodes of mild respiratory difficulty.

The infant was last examined Feb. 9, 1953. He had been hospitalized three times since operation for apparent respiratory infections. There had been many less severe episodes of wheezing and difficulty in breathing. The child's personal physician believed that he was sensitive to dust and bacteria and was undertaking a program of desensitization.

On examination the child was well developed and active. Breath sounds were decreased over the left chest but physical examination otherwise showed only normal findings.

Chest films exposed at this time showed mild generalized emphysema with increased emphysema at the left base (Fig. 6). There was slight compression of the left hemidiaphragm posteriorly. Fluoroscopy confirmed these findings. The diaphragms moved normally. There was no mediastinal shift with respiration.

CASE 3.—

History.—S. F., U. H. No. 725125, a 3-month-old white female infant, was admitted to the Pediatric Service of the University Hospital April 8, 1952, with a history of difficult respiration. The infant was born Dec. 27, 1951, following a normal pregnancy and an uncomplicated delivery. The infant weighed 6 pounds, 9 ounces at birth. It was thought that there was slight blueness about the mouth and questionable discoloration of the forehead shortly after birth. No other abnormalities were noted during the first seven weeks of life except that the infant nursed poorly.

Feb. 13, 1952, when she was 7 weeks old, she developed symptoms resembling a mild upper respiratory infection. Twelve hours later, while feeding, she became dyspneic and cyanotic. The infant was immediately taken to another hospital in a state of collapse. She had severe respiratory distress and was in critical condition. On admission to the hospital it was felt that she had massive collapse of the right lung. Bronchoscopy was carried out but no abnormality was found. The infant was finally resuscitated and thereafter slowly improved. After three weeks she was discharged. Ten days later wheezing respirations developed again and the infant became cyanotic. Following temporary admission to another hospital she was transferred to the University Hospital.

Family History.—Two brothers, four and five years of age, were normal. There was no family history of allergy or of congenital abnormalities.

Physical Examination.—Temperature was 100° F. (rectally); pulse, 146; respirations, 36.

The infant was well developed and was in no acute respiratory distress. However, respirations were rapid and were moderately labored. The infant's color was dusky when she cried. On examination there was hyperresonance to percussion over the left chest. Breath sounds and tactile fremitus were reduced over the left chest. The mediastinum was shifted to the right. The remainder of the physical examination showed only normal findings.

Laboratory.—Kahn test was negative; hemoglobin, 9.8 Gm.; red blood cells, 3.9 million; white blood cells, 9,400 with 43 per cent polymorphonuclear leukocytes, 55 per cent lymphocytes, and 2 per cent eosinophils; urine, normal findings.

Roentgenograms.—Chest films exposed at another hospital during the infant's original acute illness showed marked emphysema of the left upper lobe with mediastinal shift to the right. Inspiratory and expiratory films, exposed Feb. 22, 1952, were interpreted as showing emphysema of the left upper lobe with atelectasis of the left lower lobe. The heart and mediastinum were shifted to the right. These changes were more marked on expiration. It was believed that an expiratory block was present. Additional films exposed at intervals presented the same appearance.

Films exposed in the University Hospital at the time of admission confirmed these findings (Fig. 7). On fluoroscopy the mediastinum shifted further to the right on expiration. The hemidiaphragms were depressed and movement limited, particularly on the left.

Course.—The infant was not acutely ill while she was in the hospital. Because she had been in desperate straits at one time and because obstructive emphysema of the left upper lobe persisted, it was felt that lobectomy should be carried out.

Operation.—On April 16, 1952, anesthesia was induced with ether-oxygen and an endotracheal tube inserted. A left thoracotomy was carried out through the fourth intercostal space. When the pleural space was entered, there immediately presented a tense mass of air-containing lung which appeared to fill the entire hemithorax. This was found to be the left upper lobe. It could not be deflated. The small left lower lobe was collapsed but it expanded when the emphysematous left upper lobe was delivered into the wound.

A left upper lobectomy was performed employing the individual ligation technique. A probe was passed easily into the left main bronchus through the stump of the left upper lobe bronchus. No gross bronchial abnormality was found. There was no external compression of the bronchus.

Upon completion of the lobectomy it was seen that the expanded left lower lobe did not fill the pleural space and that considerable mediastinal shift would be necessary to obliterate the residual space. Anterior and posterior drainage tubes were inserted. The chest was closed with fine silk. Blood loss was 154 c.c. The infant received 210 c.c. of whole blood during the operation. The infant was returned to the ward in excellent condition.



Fig. 7.



Fig. 8.

Fig. 7 (Case 3).—Preoperation roentgenogram exposed April 9, 1952. Marked emphysema of the left upper lobe is present. The left lower lobe is compressed. The mediastinum is shifted to the right, and the left hemidiaphragm is depressed.

Fig. 8 (Case 3).—Postoperation roentgenogram exposed Jan. 27, 1953. There is no emphysema. The mediastinum is shifted to the left.

Examination of the Specimen.—No gross bronchial abnormalities could be found. Bronchial cartilages were present. There was uniform, massive emphysema of the entire left upper lobe (Fig. 9). Microscopic examination confirmed the gross findings (Fig. 10). There was emphysema of the pulmonary parenchyma with dilatation of the small bronchi and bronchioles. No infection was present. Elastic tissue stains showed normal amounts of elastic tissue.

Postoperative Course.—The infant did well following operation. There were no further respiratory symptoms. The residual left pleural space was obliterated with expansion of the small left lower lobe and shift of the mediastinum to the left. The infant seemed to tire easily but eight days following operation she began to gain weight steadily. She was discharged April 27, 1952.

Course Following Discharge.—The infant was returned to the care of her personal physician following discharge. At monthly intervals she had episodes of cough and wheezing



Fig. 9 (Case 3).—Photograph of the cut surface of the left upper lobe. There is emphysema of the entire lobe.

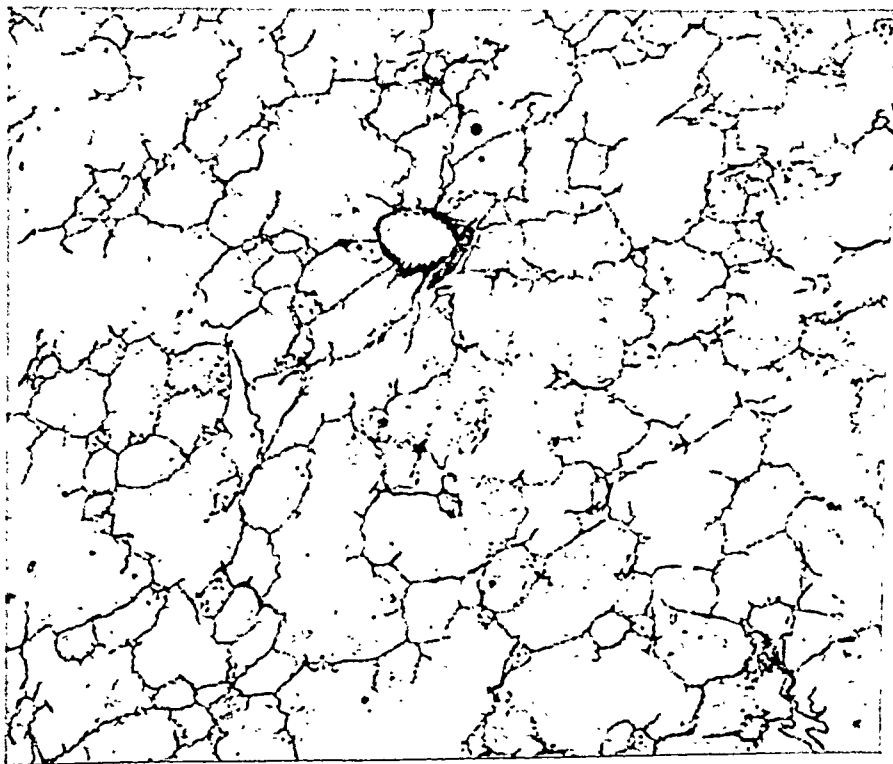


Fig. 10 (Case 3).—Photomicrograph of a section of the left upper lobe. Marked emphysema is present. There is dilatation of a small bronchus. No infection is seen ($\times 75$).

respirations which were believed to accompany respiratory infections. She was not cyanotic. Development was normal. The infant was last examined Jan. 27, 1953. At this time she was normal except for evidence on physical examination of mediastinal shift to the left.

Films exposed at this time confirmed the pronounced mediastinal shift to the left with herniation of the right lung across the anterior mediastinum (Fig. 8). On fluoroscopy there was diminished movement of the left hemithorax which seemed smaller than the right. The hemidiaphragms moved well. There was no shift of the mediastinum with respiration. There was no evidence of emphysema.

CASE 4.—

History.—F. L., U. H. No. 729545, a 2½-month-old white male infant, was admitted to the Pediatric Service of the University Hospital June 16, 1952, with a history of coughing and cyanosis. The infant was born at term March 27, 1952, following a normal labor. He weighed 7 pounds, 4 ounces at birth. The infant nursed well and was discharged home five days after birth.

Soon after he reached home it was noted that he breathed heavily. When he was 4 weeks old he began to have more difficulty breathing. He grew progressively worse. Four days after the onset of the illness the infant became cyanotic during feeding. Other, similar episodes followed. The child was admitted to another hospital where he received penicillin but did not improve. He was finally transferred to the University Hospital.

Family History.—A sister, 5½ years old, and a brother, 2½ years old, were well. There was no family history of allergy or congenital abnormalities.

Physical Examination.—Temperature, 99.2° F. (rectally); pulse, 144; respirations, 46.

The infant was well developed. Respirations were rapid and labored. He was slightly cyanotic. The percussion note over the right chest was hyperresonant and breath sounds were markedly diminished. The mediastinum was shifted to the left. On auscultation of the heart there was a harsh, systolic murmur over the entire precordium. This was loudest at the apex. It radiated up the left border of the sternum. The liver edge was palpated 3 cm. below the right costal margin. The remainder of the physical examination was within normal limits.

Laboratory Data.—Kahn test was negative; hemoglobin, 10 Gm.; red blood cells, 3 million; white blood cells, 6,000 with 32 per cent polymorphonuclear leukocytes, 67 per cent lymphocytes, and 1 per cent eosinophils; urine, normal findings.

An electrocardiogram obtained June 17, 1952, showed a heart rate of 140. The P-R interval was 0.12 and the QRS, 0.07. There was slight right axis deviation, but the tracing was within normal limits for an infant of this age.

Roentgenograms.—The infant was fluoroscoped June 17, 1952. Both lungs appeared somewhat hyperaerated, although this was more marked on the right. Both hemidiaphragms were low and motion of each was restricted. There was mediastinal shift with respiration. Films exposed at this time confirmed the fluoroscopic findings (Fig. 11). These examinations were repeated June 26, 1952, and the same findings noted. It was felt that the infant had bilateral emphysema but that this was much more marked in the right middle lobe.

Bronchoscopy.—On July 2, 1952, the infant was bronchoscoped with a 3.5 mm. bronchoscope. The bronchi collapsed with each expiration. No other abnormalities were noted in the major bronchi.

Course.—During the infant's stay in the hospital he did well as long as he remained in oxygen. When he was removed from oxygen he became cyanotic, particularly when he cried. During these episodes he developed a wheezing cough and became progressively more dyspneic and cyanotic. He was relieved when oxygen was then administered. The infant was believed to have a congenital heart lesion, probably an interventricular septal defect. However, in spite of the evidence of bilateral emphysema in the roentgenograms, it was felt that the respiratory distress was due primarily to the marked emphysema of the right middle lobe.

Operation.—On July 8, 1952, a right thoracotomy was performed through the fifth intercostal space. Ether-oxygen anesthesia was administered through an endotracheal tube. As the chest was opened the greatly distended, tense right middle lobe was seen to fill the entire pleural cavity. The right upper lobe and the right lower lobe were compressed, although they contained air. The middle lobe could not be compressed. The upper and lower lobes expanded when the middle lobe was delivered into the wound.

A right middle lobectomy was carried out by the individual ligation technique. No bronchial abnormality was found. The bronchus was of normal caliber and contained cartilage rings. As the bronchus was being exposed, there was difficulty with the infant's airway. Cyanosis and cardiac slowing resulted. As soon as the airway was re-established, the infant improved. Lobectomy was then completed without further incident. The right upper lobe and the right lower lobe easily filled the pleural cavity. Anterior and posterior drainage tubes were inserted. The chest wall was closed in layers with fine silk. The blood loss was 82 c.c. The infant received 120 c.c. of whole blood. He was returned to the ward in good condition.



Fig. 11.



Fig. 12.

Fig. 11 (Case 4).—Preoperation roentgenogram exposed June 17, 1952. There is bilateral pulmonary emphysema which is most marked in the right middle lobe.

Fig. 12 (Case 4).—Postoperation roentgenogram exposed Jan. 15, 1953. Moderate bilateral emphysema persists. The pulmonary emphysema is most marked in the lower lobes.

Examination of the Specimen.—No gross bronchial abnormality was found. There was marked, diffuse emphysema of the entire middle lobe (Fig. 13). On section there was emphysema of the pulmonary parenchyma with dilatation of the small bronchi and bronchioles. Heavy plasma cell infiltration was seen about one bronchiole. Elastic tissue stains showed normal amounts of elastic tissue to be present.

Postoperative Course.—The infant did well following operation. He soon began to gain weight and had no further respiratory symptoms. He was not cyanotic out of oxygen. However, films of the chest exposed July 15, 1952, were still interpreted as showing evidence of emphysema of both lung fields. The infant was discharged July 19, 1952, eleven days following operation.

Course Following Discharge.—The infant did well following discharge. For a time he had rare episodes of shortness of breath and slight cyanosis. He had frequent upper respiratory infections. More recently no cyanosis has been noted. The infant was last examined

Jan. 15, 1953. Development was normal. The heart sounds had not changed. Breath sounds were decreased below the right scapula.

Fluoroscopy was carried out and again it was felt that there was a moderate degree of emphysema bilaterally, particularly in the lower lung fields. There was no mediastinal shift with respiration. Movements of each hemidiaphragm were limited. Films confirmed these findings (Fig. 12).



Fig 13 (Case 4).—Photograph of the cut surface of the right middle lobe. Emphysema of the entire lobe is present ($\times 75$).

DISCUSSION

The clinical pictures presented by these four infants were strikingly uniform. Respiratory difficulties began early in infancy. The infants had labored respirations, wheezing, cough, and cyanosis. The onset of symptoms was thought most frequently to be related to a respiratory infection, but none of the infants had such an infection when examined at the time of admission. The use of antibiotics did not produce any striking improvement in their condition. On physical examination there was hyperresonance to percussion over the involved hemithorax with diminution of breath sounds on auscultation. An expiratory wheeze was often present when the infants cried.

Roentgenograms and fluoroscopy of the chest showed extensive emphysema most marked in a single lobe. This emphysematous lobe filled the entire hemithorax. There was compression of adjacent lung tissue. The mediastinum was shifted to the opposite side. The hemidiaphragm on the affected side was depressed. Shift of the mediastinum with respiration could be demonstrated

in two of the infants. In none of the infants was there clinical or roentgenographic evidence of regression of the emphysema prior to operation, and in two of the infants progression of the emphysema occurred. The emphysema was thought to be obstructive in nature.

This clinical and roentgenographic picture, once understood, was easily recognized. However, in each case there had been confusion about the diagnosis at some time during the infant's illness. Most frequently it was thought that the infant had a large pulmonary cyst. On other occasions it was felt that atelectasis or pneumonitis was present in the compressed lobes and that the emphysema was compensatory. In one infant a diagnosis of massive collapse of the opposite lung was made.

Two of the infants were bronchoscoped prior to operation. The only abnormality noted was a tendency for the bronchi to collapse during expiration. No local obstruction was seen. A third infant was bronchoscoped at another hospital and was reported to have a normal bronchial tree.

No attempt was made in any of the infants to decompress the emphysematous lobe by thoracentesis prior to operation. Such an attempt would appear to be inadvisable. In several instances in which thoracentesis was attempted by others in similar patients, a complicating tension pneumothorax occurred which made the infant's condition more precarious.^{11, 14} Effective decompression of an emphysematous lobe would be difficult to accomplish by thoracentesis.

Despite careful examination of the lobes at the time of exploration and following removal, no specific bronchial obstruction producing a check valve was found in any of the specimens. Abnormal flaccidity of the bronchial walls was probably responsible for the obstructive emphysema observed. This bronchomalacia may have been the result of abnormal cartilage rings.¹⁸ The observation that the bronchial walls collapsed on expiration in the two infants bronchoscoped before operation supports this conclusion. All of the specimens showed similar microscopic changes. There was uniform, marked emphysema with dilatation of the small bronchi and bronchioles. Elastic tissue stains showed normal amounts of elastic tissue to be present. There was little infection in the bronchi and none in the distended alveoli.

A number of etiological agents have been implicated by others in an attempt to explain the obstructive emphysema present in their patients. As causes of obstruction the following abnormalities have been listed: (1) absent or abnormally soft bronchial cartilage rings, (2) a redundant flap of bronchial mucosa, (3) compression of the bronchus by an abnormal vein, and (4) compression of the bronchus by the ductus arteriosus. However, in several of the reported cases no bronchial obstruction could be found.

The course of these infants following discharge has been in decided contrast to that reported by other authors. All of the infants did well in the immediate postoperative period; in each, the respiratory symptoms were completely relieved. Following discharge the infants remained improved and none had a return of the severe symptoms which were present before operation. Despite this improvement, each of the infants seemed more prone to develop respiratory infections and had more marked symptoms with each infection

than would have been anticipated in a normal infant. Two of the infants were admitted to the hospital several times with wheezing respirations and dyspnea. These symptoms appeared to accompany a respiratory infection. Sensitivity studies on two of the infants disclosed no specific allergies.

Roentgenograms of two of the infants following operation showed emphysema in other areas of the lung fields. This has persisted without significant change. The emphysema was felt to be more than could be attributed to compensatory emphysema following expansion of collapsed pulmonary tissue after operation. In a third infant there was evidence of mild generalized emphysema during a respiratory infection.

It would appear that the bronchial abnormality which produced the primary lobar obstruction involved other bronchi and, perhaps, the entire bronchial tree to a lesser degree. The symptoms which these infants had following operation may have been due to flaccidity of other portions of the bronchial tree. The tendency toward obstruction during expiration probably was accentuated by respiratory infections.

SUMMARY

1. Severe obstructive emphysema, most marked in a single lobe, has been observed in four infants. In two of the infants the left upper lobe was involved; in two, the right middle lobe.

2. Lobectomy was performed successfully in each of the infants, the youngest having been 6 days old and the oldest 8 months old.

3. Each of the lobes removed showed marked, generalized emphysema. Infection was not present. No specific bronchial obstruction was found. It is believed that the obstructive emphysema present was due to a check valve mechanism produced by abnormal flaccidity of the bronchi.

4. Each of the infants was improved by lobectomy. However, all had respiratory symptoms following discharge. In two of the infants there was roentgenographic evidence of emphysema in other portions of the lungs following operation. It is suggested that the bronchial abnormality also involved other portions of the bronchial tree.

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DISCUSSION

DR. PAUL C. SAMSON, Oakland, Calif.—Dr. Sloan's paper is most interesting, and I would like to discuss it, not because it involves infants but perhaps because the question of congenital emphysema is under discussion.

I would like to report a case involving a young man who came to me primarily because of a pectus excavatum (and in that connection perhaps Dr. Shaw will say something). There may be a connection between congenital lobar emphysema and pectus excavatum; we do not know.

(Slide.) This patient, aged 21, showed on his x-ray pictures a large area in which the lung markings were relatively meager and we thought this was some type of cystic disease.

(Slide.) This shows the marked pectus, and again that there is lack of normal pulmonary markings in the right mid lung field. We decided to do an exploratory operation first, and performed a right thoracotomy.

(Slide.) Much to our surprise we found an enormous middle lobe which went from apex to base and, as you see, even out of the chest. The lobe is tremendously blown up. Grossly and microscopically this was congenital emphysema insofar as we could tell, because of the fact that there was diffuse widening of all the alveolar spaces and relative lack of bronchial elements.

(Slide.) Six months later we repaired the pectus with a strut, after the manner of Dailey, using a bone bank bone, and the patient has remained well. I have no words of wisdom on this, but it is of interest in that the patient had both a pectus and apparently congenital localized emphysema of one lobe.

DR. ROBERT R. SHAW, Dallas.—I have enjoyed this paper by Dr. Sloan, largely because of the fine manner in which he has presented the problem and also because of the interest I have had in this condition for several years. I would like to present two cases to help point out the differentiation between this condition and the usual type of obstructive emphysema that we see with thick viscid mucus in the bronchi of an infant.

(Slide.) This case is very similar to the first case shown by Dr. Sloan. The child was three months old and the only symptom was rapid respirations and wheezing. There had been no evidence of infection at any time and the child was developing well. The diagnosis of emphysema on the right had to be made by a correlation of the physical findings of no breath sounds on the right, with very good breath sounds on the left, which seems a paradox when one looks at the films of the chest.

(Slide.) This shows the right middle lobe removed from this 3 month old infant. It filled the right hemithorax entirely, compressing the upper and middle lobes which were not air containing. The child has done well since surgery and has had no further respiratory difficulty. She is now a little over 2 years old.

(Slide.) Here we had an opportunity to observe the permanence of this situation. The slide on the left shows a child 2 weeks of age. At that time it was thought that an enlarged thymus was causing the obstructive type of breathing and x-ray therapy was given. It was not noticed that there was a translucency in the upper part of the left lung field. The second slide shows an x-ray picture taken when the child was 2 years old, and the same translucency is present with the heart still shifted into the right chest.

(Slide.) On the left is shown the child at the age of 4, so there had been an interval of two years between these x-ray views, and there is still translucency on the left, persisting in proportion to the child's growth. I found that the apical posterior segment of the left upper lobe was involved and was easily stripped away from the remaining portion of the lobe. Because of a severe pectus excavatum which had developed during the four years of growth, the heart was unable to go back into the left chest. Surgery for this condition was advised but the parents were so pleased with the respiratory improvement that nothing further has been done.

(Slide.) I think it is very important to differentiate this condition from the temporarily plugged bronchus which can also cause an emphysema in infants. I am wondering how Dr. Sloan was able to differentiate in the 6-day-old child these two different pathologic entities. Here is a child 2 days old with apparent emphysema of the left lung. The child was put in moist vapor and observed for one week.

(Slide.) This shows the chest at the end of one week of treatment. The emphysema has completely cleared. Just this past week I saw a child with atresia of the esophagus, who also had emphysema of the left lung. The emphysema has completely cleared following repair of the atresia. A temporary situation due to a thick viscid mucus plug causing an obstructive phenomenon must be differentiated from the more permanent type of condition that we have called localized hypertrophic emphysema.

DR. JOHN S. HARTER, Louisville.—We have had five of these infants in the past seven years. One reason for the large number is the fact that one family produced two of them. Three of the cases are of interest.

(Slide.) This 5-month-old baby was admitted to the hospital on Dec. 20, 1949, with a history of progressive dyspnea for three weeks. X-ray examination of the chest revealed a cyst occupying the entire right pleural cavity and displacing the heart and mediastinal structures to the left. There is trabeculation throughout the right lung field typical of emphysema. Because the child was admitted about 2:00 A.M. after a trip from the southern part of the state, a catheter was inserted and it was thought that operation would have to be performed later. However, the normal lung expanded and no further operative procedure was necessary.

(Slide.) The follow-up of this patient in 1952, four years after treatment by aspiration alone, revealed the child to be well with no recurrence of the cyst. This is shown because of the possibility of treating these patients by that method.

The second patient was 23 months of age and was admitted to the hospital on May 17, 1950. The parents gave a history of the child having had pneumonia three weeks previously. During the ten days before admission the baby became increasingly dyspneic.

(Slide.) X-ray views of the chest revealed a cyst occupying the right pleural space, displacing the heart and mediastinal structures to the left. At thoracotomy the right middle lobe was found to be greatly emphysematous, filling the entire right chest. A right middle lobectomy was performed. What was thought to be an incidental finding at the time of operation, was a small fibrin ball free in the pleural cavity. Thorough search of the entire pleural cavity failed to reveal any other pathologic change.

(Slide.) Much to our surprise, this photomicrograph of the fibrin ball was interpreted as sarcoma. The next slide is a high-power photograph of the fibrin ball.

The baby made an uneventful recovery and was discharged from the hospital after two weeks, with a small amount of pleural fluid present. At six weeks a checkup showed considerable fluid in the right chest. Aspiration of the fluid again revealed tumor cells. We told the family of the fatal prognosis but they refused to believe it and took the child else-

where, where it was operated upon and died three days after operation, at which time a large sarcoma of the chest was found.

The third patient was a sister of this child, who at 10 days of age was admitted to the hospital, extremely dyspneic.

(Slide.) This was also a right middle lobe emphysema and a right middle lobe lobectomy was done. This child has remained well to date.

The last two patients were sisters and one of them died of sarcoma following operation.

The first patient presented, with the catheter drainage only, suggests that the etiology of obstructive unilobar emphysema may in some instances at least be a failure of the remaining lobe or lobes to expand normally following birth. Certainly this child has remained perfectly normal for four years. The two sisters with the emphysema of the same lobe, one with sarcoma of undetermined origin, suggest the possibility of some congenital anomaly.

DR. WILLIAM A. JOHNS, Richmond.—I wish to thank the Association for allowing me as a guest the privilege of the floor. We have had the opportunity of seeing one patient similar to the ones reported by Dr. Sloan. It is interesting to note in the literature on the subject that all cases not treated by surgical excision died.

Our case was that of a 9-year-old girl whose chief complaint was frequent episodes of vomiting and nervousness. (Slide.) The anteroposterior view of the chest preoperatively shows the heart and mediastinal structures shifted to the left, the lesion being in the left upper lobe. The lower lobe is compressed.

(Slide.) The roentgenogram and photograph of the removed specimen, taken about one hour after removal, show that the lobe is not collapsed and has the appearance of Gelfoam, as described by Shaw. The apical segment was not involved in the process.

(Slide.) These are the low- and high-power photomicrographs of the cut specimen. The alveoli are dilated and the walls are thin. The walls of the bronchioles are thin and the lumina are dilated. The lining cells consist of respiratory epithelium.

(Slide.) Here is the postoperative view of the chest one month after operation, showing that the heart and mediastinum have returned to normal position, and the left lower lobe has almost completely filled the thoracic cage. No definite obstruction in the bronchi could be found. The patient has done exceedingly well since operation.

DR. RICHARD H. SWEET, Boston.—I hesitate to enter upon this discussion but it seems to me that it would be of interest to come back to the fundamental question of etiology. I would be interested also to know what Dr. Sloan says about Dr. Harter's cases, because I do not believe he is talking about the same disease.

(Slide.) Here is an inspiration-expiration film showing the paradoxical motion on the left side of a young boy of 17. He had a lot of dyspnea on exertion. The same thing is shown in the lateral view.

(Slide.) This is the slide I wanted to show principally because we were able to show in this patient that the entire lung was involved. The bronchial cartilages are completely deficient. There was no single cartilage which had the usual U-shaped arch in continuity. The bronchial wall was soft and compressible, just as much so anteriorly as posteriorly, and I feel certain that this enormous overdistention and emphysema was due to the fact that the bronchus had no stability and performed in this abnormal manner because of lack of adequate cartilage.

DR. ROSS ROBERTSON, Vancouver.—I think it is a great compliment to the excellence of Dr. Sloan's paper that it has stirred up so much discussion. I am particularly interested in this subject.

(Slide.) This is a photograph of an autopsy performed on a child at the Sick Children's Hospital in Toronto in 1933. This child at the age of two weeks had suffered from shortness of breath and cyanosis. The right chest had been aspirated repeatedly in the belief that a cystic lung was present, but the child died. This autopsy picture shows very well the huge right upper lobe almost filling the chest, compressing the lower lobe down onto the diaphragm and compressing the left lung into the left gutter.

(Slide.) This shows a section of the right upper lobe bronchus. The autopsy was performed by Dr. Erb, the pathologist, and he came to the conclusion that this flap of mucosa which is directed distally formed a ball-valve obstruction and caused the emphysema.

(Slide.) This is an x-ray view of a patient 2 weeks old who had symptoms similar to the other patient described. You will note that the lower lobe is compressed down against the diaphragm. You can differentiate this from a traumatic surgical emphysema and hemothorax by the fact that the lung is compressed downward instead of into a ball at the hilus. It can also be differentiated from atelectasis of the other lung by the fact that the diaphragm is lower; and from cystic disease in that you can see the lung markings faintly, and there is no evidence of cyst.

Caffey has suggested that regional obstructive emphysema is usually lobar rather than segmental in distribution because of the alveolar pores of Kohn which form communicating channels between the lobar segments. Consequently, if a segmental bronchus were obstructed by a congenital check-valve, symptoms would not occur unless the pores of Kohn were obstructed by some inflammatory process. From this reason uncomplicated emphysema is lobar in distribution.

DR. J. L. EHRENHAFT, Iowa City.—In the last eighteen months we have encountered six newborns and infants with the condition under discussion; I would like to show some slides.

(Slide.) The first slide shows the preoperative chest x-ray photograph of a 5-month-old infant who has, as you will see later, congenital cystic disease involving the left upper lobe of the lung. You see the marked displacement of the mediastinum to the right with compression of the contralateral lung. This child showed extreme respiratory distress when first seen by us.

(Slide.) This slide shows the operative procedure in progress. It demonstrates the greatly enlarged left upper lobe and the compression of the normal left lower lobe. The left upper lobe, particularly the anterior pectoral segment and the subapical segments were involved and showed multiple smaller and larger cystic structures.

(Slide.) This is a photomicrograph of the tissue removed by segmental resection, demonstrating that this lesion was not obstructive emphysema but true congenital cystic disease.

I would like to show you also the chest x-ray films of another patient, 12 days of age. This child also was extremely ill when seen by us. If you compare the two chest x-ray films on the slide you will see marked progression of the area of emphysema in the right hemithorax. The time between the two chest x-ray pictures is twelve hours. The pathologic examination after the markedly emphysematous right middle lobe had been resected revealed it to be true emphysema, probably obstructive in type. These children are extremely ill and die a progressive anoxic death unless rapid surgical intervention is available.

I would like to inject a word of caution. We have observed that the interval between preoperative intratracheal intubation for anesthesia purposes and the time of opening the chest is an extremely critical one. Apparently during positive pressure anesthesia, further rapid expansion of the emphysematous area does occur. This is immediately relieved as soon as the thoracic cage is opened and the remainder of the lung tissue is permitted to expand. In the patients we have seen, the history of forceful resuscitative measures in the post-partum period has been elicited. Therefore, we became interested to see if some of the emphysematous damage may be due to resuscitative measures.

I would like to show you two slides demonstrating these points. The first one is from a newborn infant who died two hours after birth. It had forceful resuscitative measures and it demonstrates the marked emphysematous changes in the lung parenchyma. In the second instance, you will see the microscopic appearance on the slide. Forceful resuscitative measures were also employed. It demonstrates marked interstitial emphysema and areas of unexpanded lung tissue. We are convinced that irreparable damage can be caused in the immediate post-partum period by overforceful resuscitative measures.

DR WILLIAM HENRY, Lynwood, Calif.—I too would like to thank the Association for the privilege of discussing Dr Sloan's paper. I have had experience with one patient, a 10 year old boy with emphysema localized to three separate areas of the right lung. One was in the right upper lobe, two in the right lower lobe.

(Slide) This is the chest film. At this time it was thought that the patient had obstructive emphysema due to an intrabronchial foreign body. Bronchoscopy was carried out and no abnormality was found. Following a bronchogram it was thought that he had cystic disease of the lung and a right thoracotomy was performed.

(Slide) This is the artist's conception of the operative findings. As nearly as I could determine the emphysema involved the posterior segment of the right upper lobe, and the lateral basal and superior segments of the right lower lobe. At that time, a little over a year ago, I did not know much about this disease. Resection of the three areas was carried out from the periphery inward. This was done very easily (not that I would recommend this method of resection in every case) as in this particular type of disease the line of demarcation with the normal lung is extremely simple to follow.

(Slide) This photomicrograph shows the emphysema, and the next slide is a post operative film showing the patient three months later. He has been followed for more than one year and has no symptoms whatsoever.

DR LEO ELOESSER, San Francisco—This extremely varied series of most interesting reports on infantile respiratory difficulties indicates great possibilities. The reports range from bronchomalacia to tumors, to adenopathy, to cysts, and to a most varied series of pathologic conditions. When I was younger they would have fallen into that undiagnosed limbo of diseases known as croup. I wonder whether Dr Johns means that the mortality of infantile croup is 100 per cent, because, as I understand it, there are many patients with croup who recover completely. It indicates, I think, the need for more exact diagnostic procedures, and it indicates also the possibilities of being more exact in our diagnosis before we proceed to resection. In some of these infants, especially those with a very large congenital cyst, surgical procedure was evidently indicated. In some of them, perhaps, I wonder whether the procedure was necessary, or whether they might have recovered without losing one half or one quarter of their lungs, and without being headed for the scoliosis which some of the x-rays already lead one to suspect.

DR SLOAN (Closing)—I should like to thank the discussors and answer the questions which were raised. In reply to Dr Shaw, it was not known whether the 6 day old infant presented had permanent changes in the emphysematous left upper lobe and whether he might not have recovered without operation. Had more expert care been employed and had bronchodilators been used more effectively, he might have been tided over. Operation was performed because it was thought the child was going to die.

I agree with Dr Sweet that this condition should be differentiated from the large pulmonary cysts which some of the discussors have mentioned. It should also be pointed out that thoracentesis for decompression of an emphysematous lobe may be fraught with considerable danger, as previous reports indicate.

In contrast to Dr Ehrenhaft's patients, none of the infants presented here required vigorous resuscitative measures at birth. While too vigorous resuscitative measures are an important factor in certain respiratory emergencies at birth, they played no part in the obstructive emphysema observed in these infants.

MUCOCELE, CONGENITAL BRONCHIECTASIS, AND BRONCHIOGENIC CYST

BEATTY H. RAMSAY, M.D., AND FRANCIS X. BYRON, M.D.
LOS ANGELES, CALIF.

THE LITERATURE on cystic changes in the lungs is very extensive. Several classifications and theories of etiology have been presented. There have been recent reviews of the subject, including an excellent paper by Cooke and Blades.¹ In the literature, we have been unable to find a recorded case of mucocoele of the lung or a specific reference to the presence of bronchial septa or segments of atresia in the bronchiogenic pulmonary cysts. During the past three years, we have encountered three cases of pulmonary cystic change with coexistent proximal bronchial septal obstruction. We do not believe this occurrence is unusual and coincidental. We do believe that bronchial obstruction, usually due to a congenital septum, is the common cause of pulmonary bronchiogenic cysts.

The first case, one of a mucocoele of the lung, has been reported.² The patient was a 17-year-old-girl with pulmonary tuberculosis, and x-ray examination showed a single cystic lesion in the left lower lobe. At surgery, the findings included in Case 1 were evident:

CASE 1.—M. S. was admitted to the Orange County General Hospital July 22, 1950. There were filmy adhesions between the superior and posterior segments and the adjacent chest wall. The arrangement of the lung was abnormal in the following respects: The basal segments were divided into two equal portions by a long vertical fissure; there was a partial fissure between the superior segment of the lower lobe and the basal segments; the interlobar fissure was incomplete, being totally absent in the posterior half; the bronchi of the posterior segment of the upper lobe originated from a subsegmental bronchus (most posterior) of the superior segment of the lower lobe, and thus traversed the posterior portion of the usual fissure line.

Dissection revealed smooth, rounded, pale, semitranslucent, cystlike structures, extending through the superior and posterior segments in a branching, budding fashion. When an occasional branch was ruptured during the dissection, it was found to contain a large amount of thick, whitish, mucoid material. There was absolutely no evidence of inflammation or of solid deposit.

After division of the superior segmental bronchus of the lower lobe, it was possible to visualize the origin. This was imperforate, coming to a shallow, blind, funnel-shaped pocket, the walls of which were completely smooth as were the walls of all the cystic spaces.

The entire lung had relatively little carbon deposit, but the superior segment was totally devoid of such pigmentation. All segments of the lung seemed to inflate normally, although the posterior segment deflated somewhat more slowly than the other. The blood supply, artery and veins, and the remaining hilar and pulmonary anatomy were normal. The diaphragm, pericardium, and mediastinal structures also were normal.

Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 30, 1953.



Fig. 1 (Case 1).—Posteroanterior roentgenogram. There is a circumscribed density in the left mid-lung field. An air-fluid level is present. A multi-branched density cannot be seen.

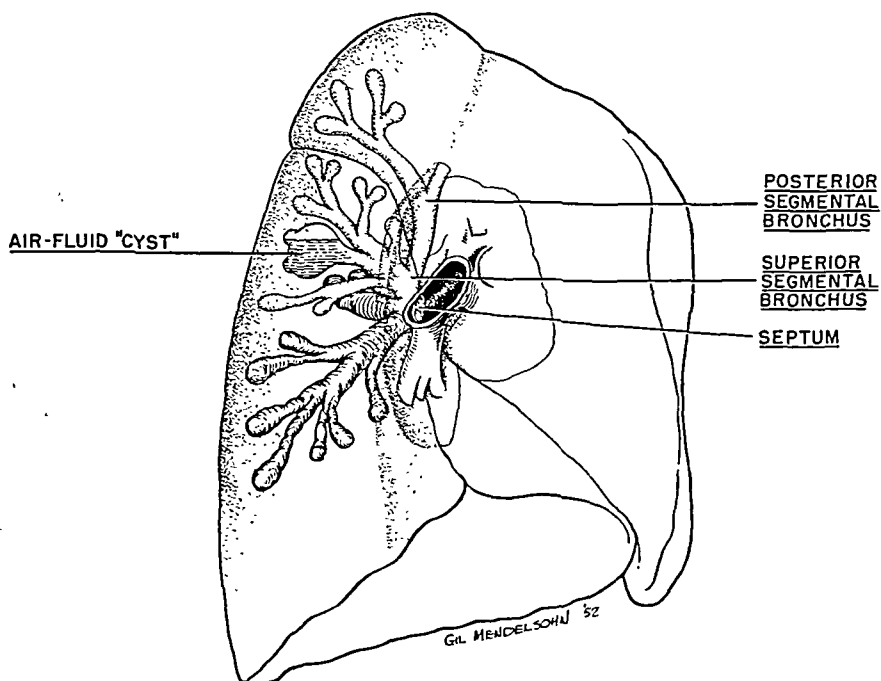


Fig. 2.—Mucocoele of the left lung. Illustration of the bronchial pathology in Case 1. The lower lobe superior segmental orifice is obstructed by a flush thin membrane. The bronchi distal to this septum are dilated and filled with mucus. One such bronchus is cystic and contains both mucus and air. The upper lobe posterior segmental bronchus terminates aberrantly distal to the septum. Both obstructed segments are normally inflated.

Surgical removal was by segmental resection. The area of bronchial obstruction was not removed. The septum was flush with the superior segmental orifice, as demonstrated by bronchoscopy, and was not removed. This septum was thin and was funnel shaped from the distal side, as one would expect from the tension of the mucus within the dilated bronchial branches.

The second occurrence was in a 30-year-old woman, asymptomatic, in whom a left pulmonary mass was discovered by survey chest roentgen-ray examination. At surgery, the following pathology was demonstrated:

CASE 2.—On April 5, 1951, R. B. was admitted to Saint John's Hospital. The pleural space was everywhere free from adhesions. The lower lobe of the lung was perfectly normal. The heart and mediastinum were perfectly normal. At the hilum of the upper lobe anteriorly, there was a cystic structure with an opaque, white wall of moderate thickness. This extended from the mediastinum outward into the lung tissue between the superior segment of the lingula and the apical segment of the upper lobe. Dissection revealed that the structure was cystic and originated from the upper lobe bronchus near its origin; at this point, there was an imperforate condition. The cystic structure itself measured about 4 cm. in diameter and split the superior pulmonary vein into two parts, one of which coursed along the inferior surface and the other along the superior surface. The pulmonary artery to the left lung also was closely opposed above and slightly posteriorly. The margins of the cyst seemed to extend right to intersegmental planes above and below, so that intersegmental veins could be followed in the separation from the superior lingular segment inferiorly, and from the remaining portion of the anterior segment above.

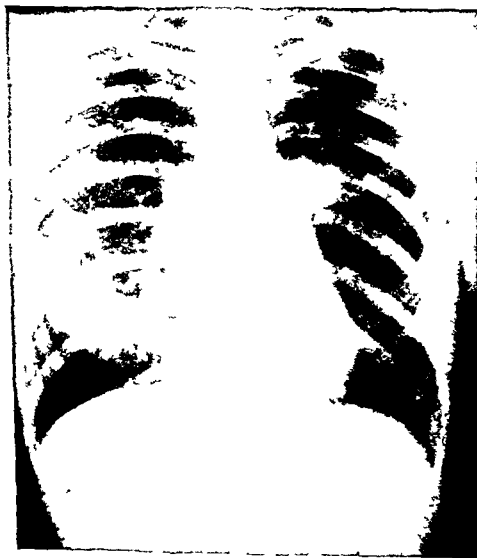


Fig. 3



Fig. 4.

Fig. 3 (Case 2).—Posteroanterior roentgenogram. There is a circumscribed left parahilar shadow of moderate density.

Fig. 4 (Case 2).—Lateral view of the circumscribed density.

There was also an anthracotic scar near the tip of the cyst and at the lower intersegmental plane. In cutting through this a small, yellowish nodule was found, resembling a small tuberculous focus, encapsulated, and measuring about 2 mm. in diameter.

The cystic structure contained a mucoid-like material and resembled, in every respect, an obstructed, small segmental bronchus filled with mucous secretions in all its branches, as it had several small, clublike outpocketings from the main cystic mass.

An excerpt from the operative description is pertinent. "However, the stump was immediately clamped distally and was sectioned proximally, and an imperforate condition of the obstructed bronchus was seen. This was perfectly airtight and it was not necessary to place any sutures here. The cyst was then removed from the upper lobe by following small veins as a guide to the upper and lower intersegmental surfaces."

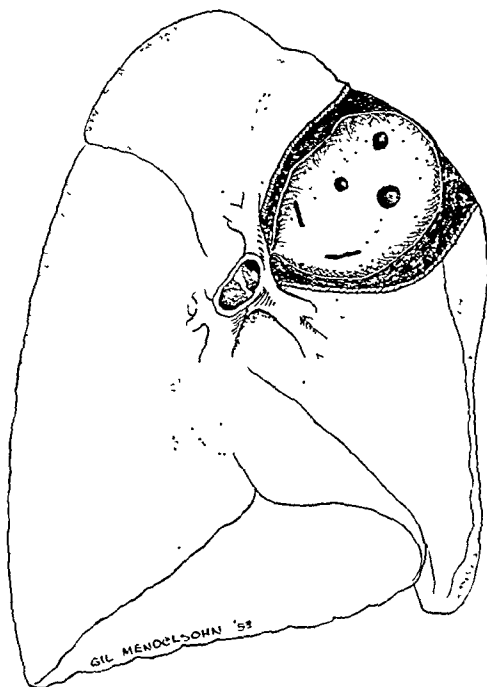


Fig. 5.—Bronchiogenic cyst left upper lobe. Illustration of the left lung depicting the cystic structure which replaces the anterior segment of the upper lobe. Note the narrow imperforate origin from the upper lobe bronchus. There are several shallow outpouchings in the cyst wall which are probably the dilated terminations of small bronchi. The wall is thickened. The intersegmental planes contain dark pigment.

The third patient was a 41-year-old man with an infected multilocular cystic mass in the middle lobe area.

CASE 3.—On Feb. 2, 1952, A. G. was admitted to Saint John's Hospital. At surgery, segmental resection of the medial segment of the middle lobe was carried out. No septum or bronchial obstruction was noted at the point of bronchial division.

Subsequently, the gross specimen was carefully examined by dissection along the bronchi. The medial segmental bronchus was normal in every respect, measured about 1 cm. in length, and bifurcated at that point. One subsegmental bronchus was dilated and thick-walled in all its branches, and at its commencement there was a rimlike circumferential thickening suggestive of residual bronchial membrane. The other subsegmental bronchus was almost completely obstructed at its origin by a thin membrane, one margin of which was in continuity with the thickening of the other subsegmental orifice. There was marked cystic change beyond the membrane, multilocular, and with varying sized out-

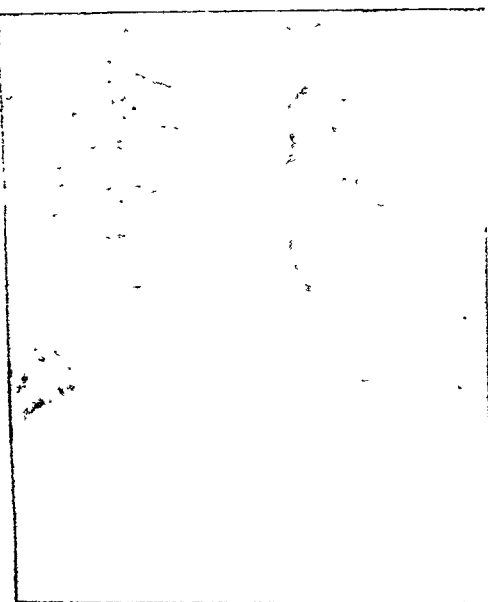


Fig. 6.

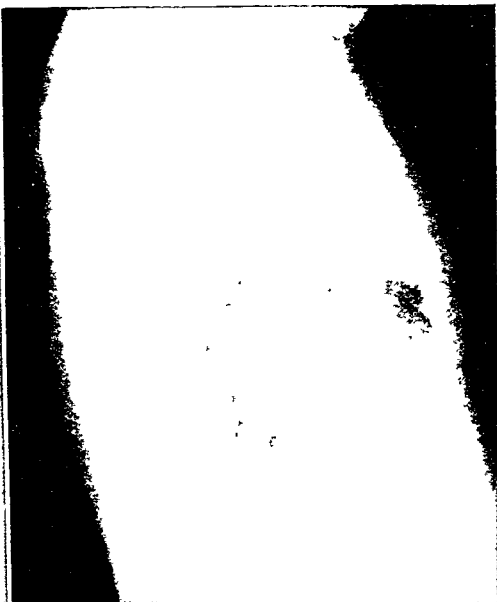


Fig. 7.

Fig. 6 (Case 3).—Posteroanterior roentgenogram. Multilocular cystic density in right cardiophrenic angle. Two fluid levels are present.

Fig. 7 (Case 3).—Lateral view again showing the two fluid levels.

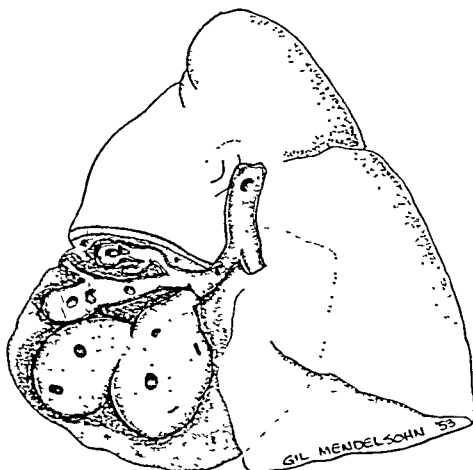


Fig. 8.—Bronchiogenic cyst and congenital bronchiectasis right middle lobe. Illustration of the right lung. In cross section the middle lobe bronchus arises from the intermediate bronchus and divides into a lateral segmental bronchus (orifice shown) and a medial segmental bronchus. The medial segmental bronchus is normally patent but soon bifurcates into sub-segmental bronchi. At the bifurcation, there is an abnormal septum.

This septum almost completely obstructs one branch, and beyond it there is multilocular cystic dilatation. The only residuum of the septum across the other branch is a rimlike circumferential thickening. Beyond this the tributary bronchi show bronchiectatic changes with transverse ridging of the mucosa, thickened walls, and dilated lumens.

The parenchyma is condensed, more so about the cyst.

pouchings. There was a 2 mm. opening in the septum, through which the cystic structure communicated with the medial segmental bronchus.

The pathologic diagnosis was bronchiectasis and cystic disease of the lung.

DISCUSSION

The three cases presented (mucocoele, bronchiogenic cyst, and combined congenital bronchiectasis and bronchiogenic cyst) appear to be variants of the same pathologic process. Each features a thin bronchial septum, intact or ruptured, along with distention in the tributary bronchi. One case presented a smooth, thin, translucent septum which completely occluded the left lower lobe superior segmental orifice; as a result, the tributary bronchial tree was distended with clear mucus.

The pathology of a second patient revealed a single cystic cavity, with outpouchings in the wall, and a thick, imperforate septum at the origin of the cyst from the bronchial tree; the cyst walls were coexistent with the intersegmental planes of separation from adjacent segments. The third entity involved the medial segment of the middle lobe; one subsegment showed severe cylindric bronchiectasis with just a trace of ruptured septum at its orifice; the other subsegment revealed an infected multilocular cystic dilatation beyond a thin septum which obstructed the orifice, a pinhead-sized opening being present in the septum.

Only in Case 3 was it practical to remove the septum as part of the resected specimen. Mistakenly the cyst, but not the septum, was photographed and studied microscopically. The portion of the specimen containing the septum was discarded. It is regretted that a photograph and a microphotograph of the septum cannot be submitted.

Although bronchial septa have not been described in connection with bronchiogenic cysts, there have been reports of numerous cases where the cystic spaces did not communicate with a bronchus. In Cooke and Blades' recent paper, two of the reported cases showed no filling of the involved segments on bronchography, and there was no record of bronchoscopic study. Perhaps a segment of bronchial atresia was present in each case. Where, in other reports, communication of the cystic spaces with the bronchus was shown, it is possible that a septum had originally been present, but had broken down. In the past, most cysts have been removed by lobectomy, and any membrane at a segmental orifice passed unnoticed. Likewise, pathologic study has usually been by cross-section technique rather than by dissection along the bronchial tree. Where resection has left a septum with the proximal stump (Case 1), it has been unrecorded.

Study of most illustrated cases of bronchiogenic cyst reveals outpouchings in the cyst walls. It is probable that these are the blind, dilated ends of tributary bronchi which have been taken up in the wall of the progressively enlarging cyst. So-called multiple cysts have been illustrated in cross-section view. It is doubtful that most of these are actually separate cysts. More likely, they are various-sized bronchial branches, dilated, distended, and tributary to a septal obstruction, and which appear to be separate cysts whe

cut in cross section. Probably examination of such cases by bronchial study will reveal the singleness of the entity.

Of all the theories which have been advanced to explain the formation of bronchiogenic cysts, the one which seems most reasonable, in light of the findings reported here, is that of Mueller, as interpreted by Sante.³ This theory holds that at a certain stage in bronchial development, the normal tubular growth is temporarily interrupted, and subsequently resumed. As a result, a zone of atresia is produced, short or long, distal to which bronchial tributaries exist. This theory and the circumstances of the clinical cases fit exactly. That portion of Mueller's theory which applies to alveolar-type cysts is not relevant to this paper.

The free and easy inflation and deflation of the two obstructed segments of Case 1 explains the lack of atelectasis and secondary x-ray change. It is probable that a mucocele is not evident on a roentgenograph until it becomes of sufficient mass to produce a significant density in relation to the amount of lung parenchyma in which it is found. Secondary changes of decreased lung volume or mediastinal shift do not occur until collateral ventilation is eliminated by edema, inflammation, or other change. Thus it would seem that a congenital bronchiogenic cyst, or its precursor, can be present in the total absence of roentgenographic change.

The deposition of anthracotic pigment in the adjacent intersegmental planes of Case 2 is probably a consequence of collateral ventilation and the filtering out of the particles by the fine mesh of the collateral openings.

In Case 1 there was a single thin-walled cystic structure, visible by x-ray examination. This contained both air and fluid. Yet at surgery, there was total bronchial obstruction and filling of the tributary bronchi with mucus. During segmental resection, unavoidably, small bronchi were interrupted and it was not possible to demonstrate the air-fluid cystic space. It must be assumed that the air entered this part of the mucocele from the alveoli, and not along the bronchial tree. It is of interest that the retained mucus does not enter the alveoli, probably due to physical properties of the mucus. Loosli, Adams, and Thornton⁴ have produced an analogous condition in dogs. By painting a lobar bronchus with silver nitrate, aseptic bronchostenosis was produced. Since no single segment of the lobe remained unobstructed, there was no opportunity for collateral ventilation, and atelectasis resulted. On pathologic examination, the larger bronchi were distended with mucus, but the terminal bronchioles and alveoli were collapsed and free from mucus.

SUMMARY

It appears clear that during bronchial development, temporary interruption of tubular growth results in formation of an atresic area beyond which normal bronchial structure exists. Progressive accumulation of secreted mucus produces cylindric distension of the blocked bronchial branches, a mucocele. If the atresic area breaks down at an early phase of distention, true congenital bronchiectasis results. If extreme distention occurs before septal rupture, there is cystic dilatation, unilocular or multilocular, and the walls of such have

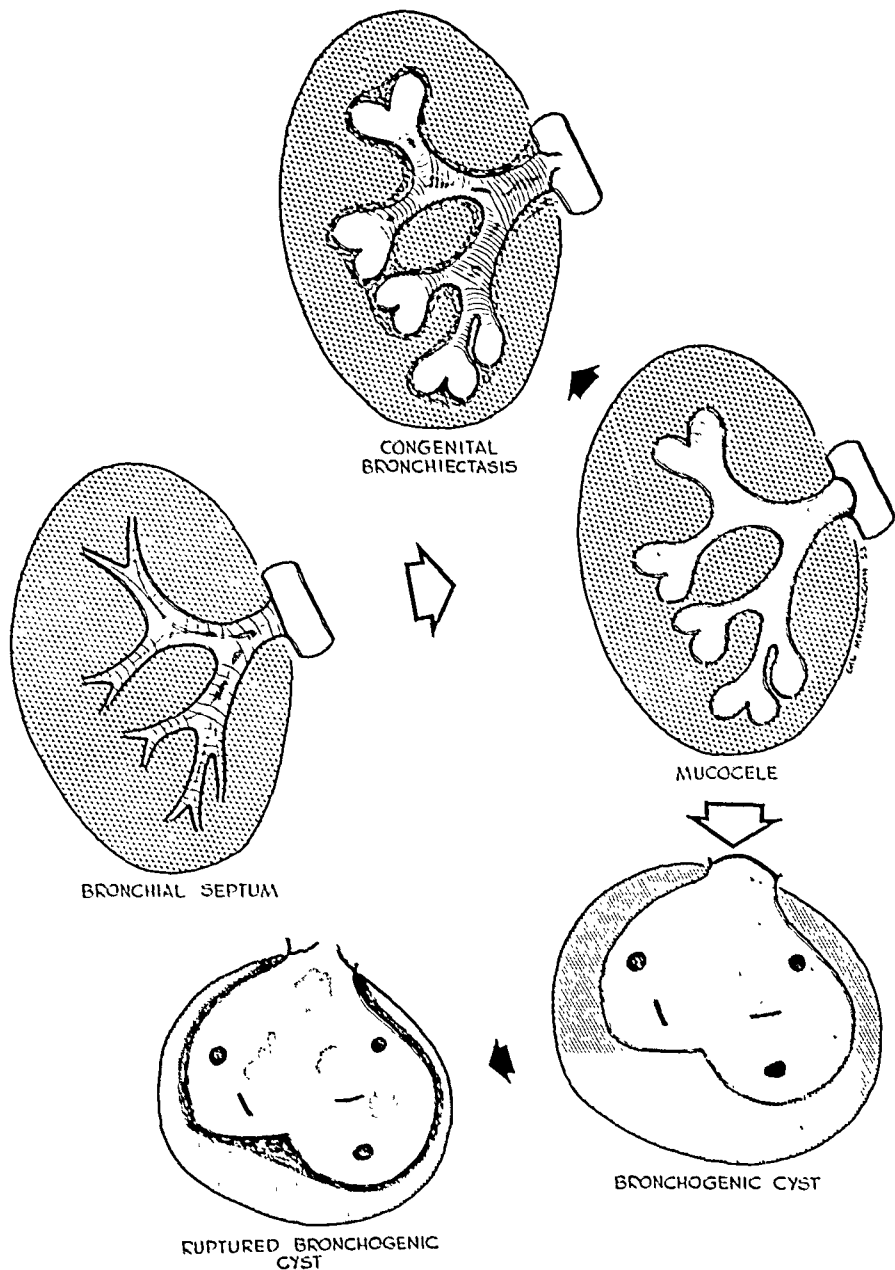


Fig. 9.—Congenital bronchial atresia, relationship of associated clinical entities. Schematic drawing. Commencing center left, follow the arrow:

Bronchial atresia: Proximally there is a segment of bronchus which failed to undergo tubular development. This area may be thin and membranous, as depicted, or longer and cordlike. Distally the bronchial wall is normal and contains functioning glands. Mucus drops are shown within the lumen. The parenchyma is normal.

Mucocele: The mucus has accumulated because of the obstruction. The septum is now convex and the bronchial walls are dilated. The parenchyma is normal.

Depending upon whether or not the septum ruptures, the following develops:

Congenital bronchiectasis: The septum of the mucocele has ruptured. Some mucus drops are still within the dilated bronchi. Infection has resulted in thickened walls.

Bronchiogenic cyst: The septum of the mucocele has remained intact and cystic dilatation of the bronchial walls has taken place. The dilated terminations of the smallest bronchi are seen as outpouchings in the cyst wall. The parenchyma is condensed but may still inflate and deflate via collateral ventilation if there are adjacent normal segments.

Ruptured bronchiogenic cyst: After cystic dilatation, the septum has ruptured. Most of the mucus has escaped. Infection has occurred with thickening of the cyst wall. The parenchyma is affected and airless.

small blind outpouchings which are the dilated terminations of the smaller bronchi.

Other findings of interest include: (1) normal inflation—deflation of the alveoli belonging to the obstructed segments, (2) the presence of an air-fluid level in one area of bronchial dilatation, and (3) failure of repeated x-ray examinations to demonstrate the branching mucocele.

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DISCUSSION

DR HENRY J. HEIMLICH, New York.—I wish to thank the Association for the privilege of the floor. I would like to refer to a case involving a patient with a congenital intrapulmonary cyst.

This child was 34 months old at the time of admission. His mother stated that at the age of one year he was admitted to a hospital with the diagnosis of pneumonia. At that time no chest x-ray picture was taken. From the age of one year until the patient's admission 22 months later, he had recurrent bouts of fever, with temperatures of 104° to 105° F., lasting one week to ten days. He always appeared undernourished and refused food after a few mouthfuls. He could walk less than a block before he had to be carried, due to extreme fatigue. He had frequent colds and cough with expectoration. Ten days before admission he had a recurrence of the fever already described. The family physician took a chest x-ray film which showed a huge collection of fluid with a fluid level in the right chest, he thought it to be an empyema.

(Slide) These are the admission x-ray films showing a huge cyst in the right chest. The third x-ray picture shows the postoperative film.

On admission temperature was 104° F.; he was given antibiotics for five days after which the temperature diminished to 101° F. At this time a thoracotomy was performed through an anterolateral incision because of the possibility of this being an empyema. A huge cyst was found within the substance of the right upper lobe which yielded thick pus on aspiration. There were only a few thin adhesions to the apex of the chest. On performing a right upper lobectomy, it was noted that the entire blood supply to the lobe consisted of two small arteries from the pulmonary artery and two small veins which entered the superior vena cava. The right upper lobe bronchus was entirely normal. There was a thin bronchial stalk from the cyst, about 2 to 3 mm in diameter, which communicated with the right upper lobe bronchus where it originated from the right main bronchus. Following lobectomy the lower lobes, which were completely free of disease and to which there were no adhesions, expanded and filled the entire chest, as was seen in the postoperative film. Recovery was uneventful and the patient's general condition consistently improved.

Pathologic examination showed the cyst to be lined with bronchial epithelium and the surrounding pulmonary tissue in the remainder of the right upper lobe to be infiltrated completely with inflammatory tissue. We feel that the presence of a normal right upper lobe bronchus and the stalk to this cyst plus its unusual blood supply puts this lesion into the class of a true congenital bronchiogenic intrapulmonary cyst.

DR ETHAN FLAGG BUTLER, Elmira, N. Y.—In bygone days, in operating upon pulmonary lesions that could be considered congenital in origin, I have five times en-

countered anomalous arteries arising from the aorta and entering lung tissue. I would like to ask Dr. Ramsay, and any other discussors if, in similar congenital pulmonary lesions, they have also noted vascular anomalies.

DR. MARK M. RAVITCH, New York.—Dr. Ramsay has demonstrated to the Association these obstructive changes in the bronchi. I am not confident that the demonstration is equally clear that these are congenital. The one patient who had tuberculosis brought to mind the fairly frequent development in children of fairly advanced bronchiectasis on which operation is ultimately undertaken, sometimes at an early age, with relatively little evidence that the obstruction is actually caused by the tuberculous process, unless one has watched the development over years with serial roentgenograms. I would like very much to hear also what the histologic changes were at the point of obstruction, and the histologic character of the lining of these cysts and bronchi.

DR. CAMERON HAIGHT, Ann Arbor.—It has been our opportunity in the last six months to see two cases of congenital bronchiogenic cysts, in which the lesions have had a solid appearance resembling a tumor. In each instance the lesion was relatively small, not over the size shown in Dr. Harter's case, and had a sharply circumscribed wall by roentgen examination. A preoperative diagnosis of probable indeterminate type of tumor was made in both cases. At operation they were found to be bronchiogenic cysts, completely filled with sterile purulent fluid and having no bronchial communication. One of them was situated in a sequestered portion of the lower lobe into which an anomalous artery entered from the aorta.

DR. RAMSAY (Closing).—I would like to thank all the discussors and will answer their questions as best I can. With reference to Dr. Butler's question about anomalous vessels, I would like to say that we have indeed encountered several cases of bronchiogenic cyst where the blood supply was anomalous. We feel that this is another type of bronchiogenic cyst, the so-called sequestration cyst. We believe the embryology, or the anomaly, is a different type entirely. That is not a part of the paper but is a part of the subject.

I cannot answer Dr. Ravitch's question too well. In two of these cases the site of obstruction had to be left physically within the patient. In the first case presented, the mucocoele was thinned and translucent, and it was almost possible to see through it; it was perfectly flush with the superior segmental orifice. It was so thin that we felt it necessary to close the proximal site with several silk sutures. In the second case the obstruction was narrowed and fibrous, it did not require closure with sutures, but it was immediately upon the upper lobe bronchus and could not be removed for study. So it was not until the third case that we had finally something from which we could make a photomicrograph. We asked the pathologist to photograph it; he sectioned it, and passed the buck to someone, who photographed the cyst but not the septum. We went back to get the specimen and they had discarded all but a small bit of the wall.

If this were a rare condition I would be more unhappy than I am because it might never be possible to demonstrate whether or not these were congenital, or just what the pathology was. However, bronchiogenic cysts are very common, and I believe if each is examined by dissecting the bronchi to the distal side, other septa will be discovered frequently, by many different people. We have a patient now on whom we hope to operate within a month, and we hope we can obtain a photomicrograph in time for publication.

In Case 1, the mucocoele was so thin and glistening that I do believe it was congenital. Our concept is, however, that proximal bronchial obstruction, whether congenital or acquired, may produce the entire sequence of changes.

With regard to Dr. Haight's interesting case, which parallels our case of mucocoele considerably, there was no bronchial communication. I would like to know if the bronchi were examined carefully, proximal to distal, and if there was an intact septum in that case.

tively. Both patients definitely improved. It is now eight and one-half months postoperatively, respectively. (It is believed that step-wise opening of the valve, about one-third of the way each time, and then checking for any resulting insufficiency might have limited this effect.)

R. F. had aortic stenosis, mitral stenosis, and a slight degree of aortic insufficiency. The latter was significantly increased by the aortic dilatation. Simultaneous mitral commissurotomy and commissurorrhaphy were performed. Death came twenty-eight days postoperatively from congestive failure, acute pericarditis, and jaundice. The aortic insufficiency, per se, was not of sufficient degree alone to cause death, but was probably contributory in the degree of congestive failure.

c. Mitral Insufficiency: Mitral insufficiency was produced in a combined case of aortic and mitral stenosis. Both valves were operated on. Recurrent pulmonary edema occurred thereafter with death four and one-half months later (Case J. M.).

d. Mitral Stenosis: In Case L. K. mitral stenosis was produced in a combined case of aortic stenosis, mitral insufficiency, and minimal mitral stenosis. Aortic commissurotomy and mitral commissurorrhaphy were performed, the latter probably too tightly. Death occurred on the second postoperative day in pulmonary edema.

e. False Passage of Guidewire Through the Interventricular Septum Out Into the Pulmonary Artery: Further attempts were unsuccessful; recovery was uneventful. Case C. R., not reported here. The aortic valve was highly calcareous. This was an earlier case which might have been successful had we used the guiding finger tip via the left auricular appendage. There was co-existent mitral stenosis, which was relieved by commissurotomy before the attempted aortic commissurotomy. The patient was a 43-year-old man. Only slight improvement occurred.

Conduction Irregularities.—

a. Ventricular Fibrillation: Case D. R. Ventricular fibrillation occurred just prior to closure of the chest after pericardium had been closed. Combined mitral and aortic commissurotomy had been performed. Suddenly there were many extrasystoles and a tremendous "jumping" and beating of the heart; then fibrillation. The pericardium was opened and massaged, and two 3 second shocks of 110 volt house line current with the defibrillator were administered. More massage was applied until there was full recovery. The intravenous procaine had been stopped two minutes prior to the onset of the fibrillation. The patient was a woman 33 years old.

Case E. S. I. The essential difficulty was aortic stenosis with a slight degree of aortic insufficiency. There was a noncalcareous valve. The mitral valve was explored and was shown to be normal; aortic commissurotomy was performed. Death occurred very suddenly, 30 minutes after surgery was completed. Immediate thoracotomy showed findings of arrest and ventricular fibrillation. Treatment included massage and mouth-to-mouth respiration. Within five minutes positive pressure oxygen and defibrillation was attempted. All efforts proved unsuccessful. Valves had been well opened as per autopsy findings. This patient presented the worst risk of any case here reported. There had been severe myocardial failure with congestive findings unresponsive to intensive medical therapy for nearly three months. The patient was a 51-year-old woman.

b. Cardiac arrest: Case F. B. The patient was a 30-year-old woman, who had cardiac arrest while mitral commissurorrhaphy was being completed. Cardiac massage and IV (intravenous) atropine brought the heart back. Mitral commissurotomy and aortic commissurotomy were then performed. There were very rapid runs of auricular fibrillation postoperatively, and a borderline schizophrenas was present for several days. Eventual recovery and control of rhythm achieved. The patient improved.

c. Auricular fibrillation: E. Sg., a 39-year-old woman, was in a shocklike state on the fifth postoperative day after an operation of combined mitral and aortic commissurotomy. Rapid IV digitalization and pressure oxygen aided in full recovery.

TABLE III. AORTIC COMMISSUROTOMIES
(APRIL 3, 1952 TO DEC. 23, 1952)

Essential Aortic Stenosis	13	J. D., R. H., F. M., P. P., W. E. I., W. Er., R. N.	7
"pure" AS			
AS, ai		E. Sl., A. W. B., L. M. (slight ai)	3
		W. I., W. C. (sl. to mod. ai)	2
		G. B. (mod. to signif. ai)	1
Essential aortic stenosis and mitral stenosis	19		
"pure" AS, "pure" MS		M. D., E. Sg., H. W., I. M. B., H. M., D. R., D. P. R., M. Gl., R. U., J. M., J. B., M. C., W. J.	13
AS, ai, MS		B. K., S. B., E. R. W.	3
AS, ai, MS, mi		M. Gn., H. S.	2
AS, MS, mi		F. D.	1
Essential aortic stenosis, mitral stenosis, and mitral insufficiency	5		
AS, MS, MI		G. D. W., F. B.	2
AS, ai, MS, MI		E. C., F. K., R. F.	3
Essential aortic stenosis and mitral insufficiency	3		
AS, MI		C. W., K. B.	2
AS, ai, MI, ms		L. K.	1
Essential aortic insufficiency and mitral stenosis	1		
as, AI, MS		J. A.	1
Essential aortic insufficiency	1		
as, AI, mi		R. C.	1
		42 cases	7 deaths
Isolated aortics	13 with 1 death:	7.7% mortality	16.6% mortality
		77.0% improved	
Multivalvular cases	29 with 6 deaths:	20.7% mortality	
		72.4% improved	

R. F. (see under aortic insufficiency) died twenty-eight days postoperatively in congestive failure, probably with recurrent rheumatic infection and pericarditis. Severe runs of auricular fibrillation postoperatively; normal sinus rhythm had been present preoperatively.

Other Complications.—

a. Retained Secretions: Five cases required bronchoscopy and one tracheotomy (particularly common in cases with pulmonary fibrosis, emphysema, or a very large left atrium pressing on the left main bronchus).

b. Pleural Effusion: There were seven cases, serous, which recovered.

c. Atelectasis: There was one case; bronchoscopy and forced coughing; the patient recovered.

d. Pulmonary Embolism: One patient, H. W., a 41-year-old man, died on the seventh postoperative day. He had had aortic and mitral commissurotomy. Ante-mortem thrombus, right auricular appendage had occurred.

e. Gastric Dilatation: There were two cases; recovery was uneventful.

COMMENTS ON TWO CASES NOT A PART OF THOSE HERE REPORTED

The mandatory relief of both valves in combined aortic and mitral stenosis is aptly shown in two such cases in which only the mitral valve was opened.

Death from ventricular fibrillation and cardiac arrest came in one case, J. I. R., a man aged 58 years, 24 hours postoperatively. At surgery, following relief of the mitral stenosis, the blood pressure fell to a level of 60 and the decision was against attempting the aortic commissurotomy. This was one of the earlier cases; today both valves would have

TABLE IV. FORTY-TWO OPERATIVE CASES—CLINICAL EVALUATION

42 CASES:	AORTIC STENOSIS (40 CASES)				AORTIC INSUFFICIENCY	
	ISOLATED OR SIG- NIFICANTLY SO	PLUS MITRAL STENOSIS	PLUS MS & MI	PLUS MI	PLUS MS	WITH INSIG- NIFICANT AS & MI
			(AS, MS, MI)			(AI)
	(AS)	(AS, MS)	(MI)	(AS, MI)	(AI, MS)	(AI)
	13	19	5	3	1	1
Sex: 23 male	11	5	3	2	1	1
19 female	2	14	2	1	-	-
Age: (average)	36.2 yr.	41.5	36.5	43.3	34	34
(range)	14-67 yr.	32-59	25-51	40-48		
20 cases: positive history of rheumatic fever	4	8	4	2	1	1
19 cases: strongly sus- pected origin of rheu- matic fever	6	11	1	1		
Other origin	2 (con- genital)			1 (Rheumat- ic fever and sub- acute bac- terial en- docardi- tis)		
3 cases						
Duration of known murmur: (average; valve un- specified)	15 yr.	14½	20	17	27	24
14 cases in myocardial failure	4	6	1	3	-	-
Duration of clinical signs and symptoms	4.3 yr.	5.5	3	9	6 mo.	10 yr.
Duration of acute symp- toms (average)	1.2 yr.	1.1	1	9 mo.	6 mo.	-
Calcification of aortic valve	9	7	2	2	1	-
Mortality (16.6%)	1	0	1	0		
Operative	0	2	1	1		
Early	0	1	0	0		0
Late	1	3	2	1	0	-
Per cent	7.7	15.8	40.0	33.3	-	-

been opened. The lack of blood pressure would have caused concern but no surgical refusal to proceed.

Another patient, R. I., a 49-year-old woman, had relief of a tight mitral stenosis, but because the aortic stenosis was considered only slight to moderate in degree, further procedure was surgically refused. Some five weeks later this patient returned in severe congestive failure, with the obvious findings of significant aortic stenosis. Attempts to get the case in condition for surgery were to no avail in spite of intensive medical care. Death came in congestive failure nearly seven weeks postoperatively.

Comment.—These two cases demonstrate in a very vivid way the physiologic significance of multivalvular heart lesions and their requirements for simultaneous repair once surgery has been decided upon as the course of therapy. They tend to justify the concepts of surgical treatment as outlined under "Concepts."

SUMMARY

1. The etiology and pathogenesis of aortic stenosis is reviewed, including autopsy findings in 6 cases of 42 aortic commissurotomies.

2. Previous efforts for the relief of aortic stenosis are discussed.
3. Confirmation of the soundness of the concept of aortic commissurotomy is presented.
4. The Bailey aortic "dilator" is described.
5. The present technique of aortic commissurotomy is outlined.
6. Forty-two cases of aortic stenosis, with and without other valvular disease, are presented; in each instance aortic commissurotomy was performed. There were included 21 cases with mitral commissurotomy simultaneously performed, 2 with mitral commissurorrhaphy, 2 with both mitral commissurotomy and commissurorrhaphy, and one with transaortic Nylon tamponage of the aortic valve.
7. Concepts and discussion of physiology and technique are given.
8. Preoperative evaluation and indications for aortic commissurotomy are considered.
9. There were seven deaths in 42 cases, a mortality of 16.6 per cent. The causes are divided as follows:

In 13 cases of isolated aortic stenosis, one death, 30 minutes postoperatively, was due to ventricular fibrillation; mortality of 7.7 per cent.

In 19 cases of aortic stenosis and mitral stenosis (17 mitral commissurotomies performed) there were three deaths; mortality of 15.8 per cent. These are accountable as follows: one two and one-half hours after surgery due to bleeding from the ventricular surgical wound; one on the seventh postoperative day from a massive pulmonary embolism due to thrombosis of the right auricular appendage; one four and one-half months postoperatively due to recurrent pulmonary edema following a significant mitral insufficiency produced at surgery.

In 5 cases of aortic stenosis, mitral stenosis, and mitral insufficiency (each lesion significant) there were 2 deaths. This small group, besides having aortic commissurotomy, included 3 mitral commissurotomies and 2 in which both mitral commissurotomy and commissurorrhaphy (mitral commissural suturing) were performed. Mortality is 40 per cent. One death occurred on the operating table, following relief of the valvular lesions, due to a tearing through of the hemostatic ventricular purse-string suture, resulting in fatal hemorrhage. The other death, twenty-eight days postoperatively, was due to reactivation of rheumatic infection with pericarditis, congestive failure, and perhaps some degree of produced aortic insufficiency.

In 3 cases of aortic stenosis and mitral insufficiency (3 aortic commissurotomies and 2 mitral commissurorrhaphies) there was one death; mortality of 33.3 per cent. This fatality occurred on the second postoperative day due to pulmonary edema probably resulting from a too tightly sutured mitral valve; a surgically produced mitral stenosis.
10. Of the isolated aortic valve cases, 77 per cent are improved. Of the multivalvular cases, 72.4 per cent are improved.
11. Operative and postoperative complications are discussed.

12. The theoretical concepts, the developmental experiences, the clinical and pathologic results of this work encourage us to hope that aortic commissurotomy for aortic stenosis will prove to be as permanently beneficial as mitral commissurotomy for mitral stenosis.

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CARDIOPULMONARY FUNCTION TESTS

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SINCE THE heart and the lungs function as a unit, it is often difficult to test them separately.

The main function of the heart and the lungs is to furnish a continuous supply of oxygen and nourishment to all cells of the body and to remove the carbon dioxide and metabolic end products.

FUNCTION OF THE HEART

The heart functions as a pump with the atrioventricular septum acting as a piston. Function tests will therefore in the first place include determinations of the pump's output and pressures in the heart and the big vessels.

The Cardiac Output.—The cardiac output is determined according to Fick's formula, $\frac{\text{Oxygen consumption ml. 'min.}}{\text{The arteriovenous } O_2 \text{ diff. ml. L.}}$. The error of the method, how-

ever, may be as much as 15 per cent in determinations at rest. To this analytic error a physiologic variation of the minute volume at two different investigations in the same subject must be added. The determination of cardiac output is, therefore, of limited value in evaluating the result of a valvulotomy. Only if the increase is more than 15 per cent may it be ascribed to the operation.

Furthermore it is difficult to compare the cardiac output at rest and during effort. If the patient at rest is anxious for a strange investigation a considerable increase of the cardiac output may result. Later on, when the patient is concentrating on limited work the cardiac output may have decreased. This decrease then cannot be ascribed to the exercise. Investigation during basal conditions is most important. Still, it is difficult to compare cardiac output at different occasions in the same subject.

The Arteriovenous Oxygen Difference.—The arteriovenous oxygen difference is a more reliable test of an adequate circulation. On two consecutive determinations in seven subjects with an interval of twenty to thirty minutes a standard deviation of 5.6 per cent was found in differences averaging 35 ml. per liter (Werkö, Bersens, and Lagerlöf, 1949). The technical errors will play a lesser role in cases with a higher arteriovenous oxygen difference. Values exceeding 50 ml. per liter at rest and 69 ml. per liter on effort are regarded as pathologic (Hickam and Cargill, 1948; Riley and his associates, 1948; and Dexter and his associates, 1951).

In cases of mitral stenosis grouped according to the New York Heart Association the following values were found (Eliassch, 1952):

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The pulmonary capillary pressure curve is of no conclusive help in the determination of the degree of mitral insufficiency complicating the stenosis.

The determination of the degree of complicating insufficiency before as well as after the valvulotomy is of utmost importance. Several laboratories are working on a technique for direct measurements in the left auricle along the following lines: 1. Retrograde catheterization from the aorta is technically impossible in most instances. 2. Introducing a needle directly into the left auricle through the anterior chest wall via the ventricle is feasible in dogs. 3. Direct puncture of the left auricle through the left main bronchus during bronchoscopy has been reported in ten cases. 4. I have used a method in which I introduce a needle paravertebrally directly into the left auricle from the right side.* Simultaneous pressure measurement in the pulmonary capillaries and left auricle shows that the pressure curve in the pulmonary capillaries closely reflects the pulse pattern in the left auricle in many cases (Fig. 1). The left auricular pressure curve seems, however, to have a more typical pattern in stenosis and insufficiency. We therefore hope that the left auricular pressure curve may be of help in evaluating the degree of insufficiency complicating a case of mitral stenosis.

The pulmonary capillary pressure is normal in cases of chronic pulmonary disease in spite of a high pressure in the pulmonary artery. A normal capillary pressure and a high pulmonary arterial pressure are also found in cases of Eisenmenger complex, that is tetralogy of Fallot without the pulmonary stenosis.

Having the patient breathe a gas mixture of about 10 per cent oxygen may produce symptoms and ECG changes in cases with coronary insufficiency.

The exercise test was introduced to measure the relationship between the pulmonary ventilation and gas exchange at rest and during exercise. Normal individuals show an increase in the oxygen uptake per liter of ventilation during effort. In patients with a mechanical obstruction to blood flow in the pulmonary artery, that is a pulmonic stenosis, the obstruction prevents a proportionate increase in pulmonary blood flow. The oxygen uptake per liter ventilation will therefore decrease during exercise (Bing). In Bing's experience 80 per cent of all patients with pulmonic stenosis showed a fall in the oxygen consumed per liter of ventilation. The value of oxygen consumed also fell in most patients with complete transposition of the great vessels.

PULMONARY FUNCTION

The main function of the lungs is a continuous exchange of oxygen and carbon dioxide between the alveoli and the pulmonary capillaries. The result of this gas exchange will immediately be visible in the oxygen and carbon dioxide tension of the arterial blood (provided cardiovascular anomalies can be excluded). Therefore an investigation of the arterial oxygen and carbon dioxide tension is important in the determination of the pulmonary function

*A detailed description of the technique will appear in *Annals of Surgery* (Björk, Malmström, and Uggla).

	NO.	ARTERIOVENOUS O ₂ DIFFERENCE
I. No symptoms	23	38.0 ± 1.42
II. No symptoms at rest		
Moderate symptoms on effort		
III. No symptoms at rest	22	52.6 ± 1.79
Pronounced symptoms on effort	9	59.9 ± 3.47
IV. Symptoms at rest		

Calculation of Shunts.—Calculation of the blood flow through the aorta and pulmonary artery and through the different shunts according to Dexter and Bing in cases of congenital malformations of the heart and big vessels will only give approximations of a very limited clinical value.

Pressure Measurements.—Pressure measurements are of the highest clinical importance. In cases with septal defects and pulmonary stenosis pressure measurements are of determining diagnostic value. Cases of mitral stenosis may be grouped according to the pressure in the pulmonary artery at rest and during effort. Such a classification is more objective and probably of more value than the one by the New York Heart Association.

A mean pressure of more than 6 mm. Hg in the right auricle is considered a sign of right heart failure.

Mean pressures exceeding 20 mm. Hg in the pulmonary artery are regarded as pathologic.

Regarding the pulmonary capillary pressure many unsolved problems remain. Dog experiments performed by Dexter suggest that the capillary pressure is almost identical to the pressure in the pulmonary veins. In cases with a high pressure in the pulmonary artery, however, this pressure may influence the capillary pressure to a certain degree. Therefore, it is not possible to decide with certainty from the form of the capillary pressure curve if a systolic pressure rise in a case of mitral stenosis with sinus rhythm is due to mitral regurgitation or a transmission of the pulmonary arterial pressure wave or to a summation of both factors.

The pulmonary capillary pressure curve does not help us to evaluate the degree of insufficiency complicating the mitral stenosis.

The pulmonary vascular resistance is calculated as follows:

Pulmonary arterial mean - capillary mean pressure × 1,332. Values exceed-

Cardiac output ml. per second
ing 200 units are considered pathologic. The degree of pulmonary arteriolar resistance will express the change in the dynamics of the lesser circulation due to the mitral stenosis and causing the clinical symptoms.

During the progressive course of a mitral stenosis an increased pulmonary arteriolar resistance is developed. This increased resistance will prevent the right ventricle from pumping more blood into the lungs than the left heart can handle, thus preventing pulmonary edema.

How much pressure measurements and arteriolar resistance determinations will influence the indications for surgery can only be shown by future experience.

of patients. The following three functions are important factors in the gas exchange in the lungs. See Fig. 2.

(1) Ventilation, (2) Diffusion, and (3) Circulation—these three functions will be discussed separately. The result of the gas exchange, however, is visible in the arterial oxygen and carbon dioxide tension.

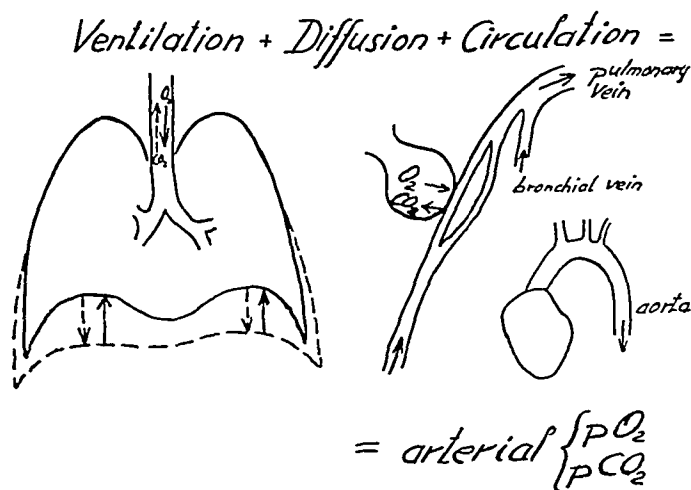


Fig. 2.—Diagram of the pulmonary function. The result of the gas exchange is visible in the arterial oxygen and carbon dioxide tensions.

To evaluate smaller variations in the oxygen contents of arterial blood the oxygen tension has to be determined. In 1951, Comroe wrote that blood leaves hyperventilated alveoli with practically no increase above normal arterial oxygen content. This opinion is based on investigations of the oxygen saturation according to Van Slyke and Neill. Therefore, it was most interesting to find a pronounced increase of the arterial pO_2 during hyperventilation. In healthy individuals there was an increase of pO_2 from 86 to 109 mm. Hg during hyperventilation while the oxygen saturation did not show any significant increase, see Table I. As such a pronounced increase in arterial oxygen tension is found during voluntary hyperventilation in healthy individuals, patients with pulmonary disease are now investigated in the same manner. It has been found so far that patients with no pulmonary reserve cannot increase their arterial oxygen tension during thirty seconds of hyperventilation. I therefore believe that the increase of arterial oxygen tension during voluntary hyperventilation is a good expression for the pulmonary reserve.

TABLE I. THE INFLUENCE OF HYPERVENTILATION ON ARTERIAL OXYGEN TENSION (pO_2) AND SATURATION ($\%O_2$) IN HEALTHY INDIVIDUALS

	NO. OF CASES	pO_2 MM. Hg	NO. OF CASES	$\% O_2$
Rest	29	86 ± 1.1	27	94.0 ± 0.4
Hyperventilation	21	109 ± 1.6	15	94.3 ± 1.0
Difference		23 ± 2.0		0.3 ± 1.1
		$P < 0.001$		$P > 0.05$

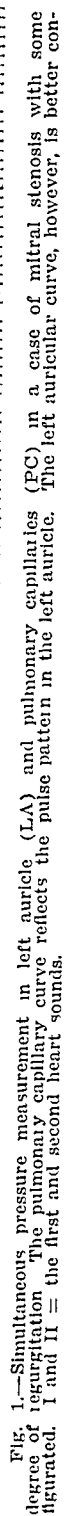


Fig. 1.—Simultaneous pressure measurement in left auricle (LA) and pulmonary capillaries (PC) in a case of mitral stenosis with some degree of regurgitation. The pulmonary capillary curve reflects the pulse pattern in the left auricle. I and II = the first and second heart sounds. The left auricular curve, however, is better con-

We use the technique of Riley, Proemmel, and Franke. The error of the method has been estimated by double determinations to 1.7 mm. Hg or 2.5 per cent of the average when single determinations are made, and to 1.2 mm. Hg or 1.8 per cent of the average when double determinations are performed.

Normal Values.—Twenty-nine healthy individuals have been examined. The mean value of arterial pO_2 was: 86.3 ± 1.08 mm. Hg (S.D. = 5.8; range 71.5 – 100.1 mm. Hg). Values below 70 mm. Hg are considered pathologic. (Mean value $- 3 \times$ S.D. = 68.9 mm. Hg.) Then an oxygenating insufficiency is diagnosed provided a right to left shunt can be excluded.

A patient with an oxygenating insufficiency has no cardiorespiratory reserve. Still, he may perform a limited amount of work.

Smaller and localized changes in the lungs will not decrease the arterial pO_2 . Even patients with more pronounced pulmonary disease as well as patients who have had a pneumonectomy may have a normal arterial pO_2 , provided the remaining lung tissue has a normal function.

It has been suggested (Comroe) that in borderline cases with a small cardiorespiratory reserve an oxygenating insufficiency should be more pronounced during effort. This has, however, not been the case in 29 normal persons and 108 patients with pulmonary disease where the arterial pO_2 has been investigated at rest and during effort.

1. In normal cases no difference is found in the arterial pO_2 at rest and during effort, see Table III.

TABLE III. OXYGEN TENSION (pO_2) AT REST AND DURING EFFORT IN HEALTHY INDIVIDUALS

	NO.	MEAN	S.D.
pO_2 at rest	29	86.3 ± 1.08	5.8
pO_2 during effort	19	85.4 ± 1.68	7.3

2. No decrease is found in the arterial pO_2 during effort in a group of thirty-four cases with oxygenating insufficiency at rest (pO_2 rest < 65 mm. Hg). pO_2 rest < 65 mm. Hg; $n = 34$; $\frac{\text{Difference } pO_2 \text{ rest} - pO_2 \text{ effort}}{-0.2 \pm 2.2, P > 0.05}$.

3. No decrease in arterial pO_2 during effort is found; either the maximal breathing capacity (MBC) is high or low, see Table IV.

TABLE IV. DIFFERENCE BETWEEN THE ARTERIAL OXYGEN TENSION (pO_2) DURING EFFORT AND AT REST

MEN	NO.	DIFFERENCE pO_2 EFFORT $- pO_2$ REST
MBC > 95	25	-0.3 ± 1.9 ; $P > 0.05$
MBC < 56	19	-7.6 ± 4.4 ; $P > 0.05$

4. If the ventilatory reserve $(100 - \frac{\text{minute ventilation during effort} \times 100}{\text{maximal breathing capacity}})$ is high no correlation is found with the arterial pO_2 during effort. In cases with a very low ventilatory reserve (< 50 per cent), however, a tendency to decreased arterial pO_2 during effort is noticed ($0.05 > P > 0.01$), see Table V.

The explanation of the big difference in the oxygen saturation and the oxygen tension determinations is to be found in the dissociation curve of the oxyhemoglobin which is very flat at high tensions. See Fig. 3.

Variations in the amount of physically dissolved oxygen will hardly be detected by the saturation method but a significant difference will be found in the oxygen tension.

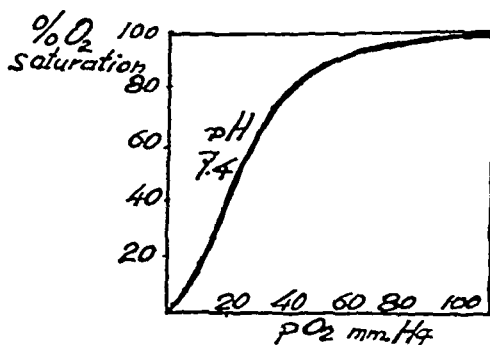


Fig. 3.—Diagram of the oxyhemoglobin dissociation curve, which is very flat at high tensions.

The sensitivity of the oxygen tension method is clearly demonstrated during heart catheterization. Blood was withdrawn from the pulmonary capillaries in sixteen patients and the mean pO_2 was 104.8 mm. Hg at the same time when blood from the brachial artery showed a mean pO_2 of only 77.6 mm. Hg. At the oxygen saturation determination no significant difference was found, see Table II.

TABLE II. A COMPARISON BETWEEN ARTERIAL OXYGEN TENSION (pO_2) AND SATURATION ($\%O_2$) IN BRACHIAL ARTERY AND PULMONARY CAPILLARIES IN 6 PATIENTS

	pO_2 MM. Hg	$\% O_2$
Brachial artery	86.4	93.4
Pulmonary capillaries	105.8	94.2

This high pO_2 value may be used to test whether or not the catheter is in the correct position for reading the pulmonary capillary pressure (Malmström and Michas).

The following factors contribute to the very high pO_2 found in the pulmonary capillaries: 1. The slow withdrawal of blood from the pulmonary capillaries will provide a longer equilibration time between alveoli and the capillaries. 2. As the circulation to this area is obstructed by the catheter, pO_2 in these alveoli will be higher than in the surrounding lung parenchyma. 3. The bronchial veins draining into the pulmonary veins will decrease pO_2 in the brachial artery compared to pO_2 in the pulmonary capillaries.

It is difficult to estimate the physiologic value of oxygen tension determinations in the pulmonary capillary blood as the two first mentioned factors are artefacts.

From this comparison of oxygen saturation and oxygen tension during hyperventilation and in pulmonary capillary blood, it is evident that only the oxygen tension of arterial blood is of value as a test of pulmonary function.

CO₂ content may be high or low in either alkalosis or acidosis, measurements of pH should always be performed to differentiate between these conditions.

Pulmonary insufficiency for CO₂ elimination is always accompanied by pulmonary insufficiency for oxygen uptake. On the other hand, the carbon dioxide content may be normal or low at times when an oxygenation insufficiency is present.

A normal arterial CO₂ content, therefore, does not exclude a very small pulmonary reserve. Then a hyperventilation of the alveoli will prevent the arterial CO₂ content to rise.

The arterial CO₂ content is higher in cases with an oxygenating insufficiency than in cases with arterial pO₂ > 80 mm. Hg; see Table VIII.

TABLE VIII. COMPARISON OF ARTERIAL CARBON DIOXIDE CONTENT IN CASES WITH HIGH AND LOW ARTERIAL OXYGEN TENSION

	NO.	pCO ₂ MM. HG	NO.	VOL. % CO ₂
pO ₂ > 80	32	37.6 ± 1.5	22	44.9 ± 0.8
pO ₂ < 65	34	44.5 ± 1.6	24	48.1 ± 1.2
Difference		6.9 ± 2.2		3.2 ± 1.4
		0.01 > P > 0.001		0.05 > P > 0.01

In cases with a high residual capacity and a low maximal breathing capacity no significant increased arterial CO₂ content was found although it was high in a few cases.

No significant change of the arterial CO₂ content during effort was found either in normal persons nor in patients with oxygenating insufficiency.

In cases with a decrease of the arterial pO₂ > 10 mm. Hg during effort an increased arterial pCO₂ was found. On the other hand, cases with an increase of arterial pO₂ > 7.5 mm. during effort showed a decreased pCO₂ at the same time, see Table IX. It is therefore evident that the influence of effort on the arterial CO₂ content is dependent on the degree of hyperventilation.

TABLE IX. COMPARISON BETWEEN INFLUENCE OF EFFORT ON ARTERIAL CARBON DIOXIDE CONTENT IN CASES WITH DECREASE AND INCREASE OF ARTERIAL pO₂ DURING EFFORT

DIFFERENCE EFFORT - REST	NO.	DIFFERENCE EFFORT - REST pCO ₂ MM. HG	NO.	DIFFERENCE EFFORT - REST VOL. % CO ₂
pO ₂ > - 10 mm.Hg	26	6.4 ± 2.4	24	-2.5 ± 1.5
pO ₂ > + 7.5 mm.Hg	22	-5.0 ± 2.4	14	-3.7 ± 1.2

Bronchspirometry.—Bronchspirometry will give information about the oxygen uptake and ventilation of each lung separately. According to Björkman 54 to 55 per cent of the oxygen uptake and ventilation occurs in the right lung in healthy individuals. The diminished oxygen uptake of the left lung is partly considered to be due to a longer left main bronchus. Baldwin and his associates consider the share of the right lung in oxygen uptake to vary from 50 to 65 per cent.

The diseased lung will show a relatively better function breathing 100 per cent oxygen, compared to the function when air is used.

TABLE V. COMPARISON BETWEEN INFLUENCE OF EFFORT ON ARTERIAL OXYGEN TENSION IN CASES WITH HIGH AND WITH LOW VENTILATORY RESERVE (100 - MV EFFORT/MBC)

	NO.	DIFFERENCE pO_2 EFFORT - pO_2 REST
100 - MV effort/MBC $> 70\%$	47	0.002 ± 1.2 ; $P > 0.05$
100 - MV effort/MBC $< 50\%$	23	-7.4 ± 2.8 ; $0.05 > P > 0.01$

5. No decrease of the arterial pO_2 during effort was found; either the residual capacity was < 30 per cent or > 35 per cent of the total capacity.

It can therefore be concluded that during effort no significant change of the arterial pO_2 is found; either the pulmonary reserve is good or bad. The explanation to this finding is that the patients by a hyperventilation during effort can keep the arterial pO_2 at a fairly constant level. This hyperventilation is more pronounced in patients with a small pulmonary reserve.

The Carbon Dioxide Content of Arterial Blood.—The determination of the arterial pO_2 according to Riley and his co-workers is not superior to the manometric method of Van Slyke and Neill. Similar differences in the CO_2 content of arterial and pulmonary capillary blood were found at heart catheterization of six patients, see Table VI.

TABLE VI. COMPARISON BETWEEN CARBON DIOXIDE CONTENT IN BRACHIAL ARTERY AND IN PULMONARY CAPILLARIES IN 6 PATIENTS

	pCO_2 MM. HG	VOL. % CO_2
Brachial artery	35.6	45.4
Pulmonary capillaries	25.9	40.0

The very low CO_2 content in the pulmonary capillary blood must be ascribed an equilibration to ventilated, but not perfused, alveoli due to the occlusion of the heart catheter.

Also during hyperventilation similar differences of the CO_2 content are found by the two methods, see Table VII.

TABLE VII. INFLUENCE OF HYPERVENTILATION ON ARTERIAL CARBON DIOXIDE CONTENT STUDIED IN HEALTHY INDIVIDUALS

	NO.	pCO_2 MM. HG	NO.	VOL. % CO_2
Rest	29	35.0 ± 1.44	26	46.8 ± 0.73
Hyperventilation	21	16.4 ± 1.71	14	36.1 ± 0.73
Difference		18.6 ± 2.24		10.7 ± 1.03
		$P < 0.001$		$P < 0.001$

These findings clearly demonstrate the importance of taking the sample when the arterial needle has been in place for some time and the patient is breathing quietly.

The arterial CO_2 content in twenty-nine healthy individuals was found to be 35.0 ± 1.44 mm. Hg pCO_2 , or 46.8 ± 0.73 volume per cent CO_2 .

High arterial CO_2 content does not necessarily mean an insufficient CO_2 elimination. It may be due to primary chloride loss with compensatory retention of CO_2 as bicarbonate, that is alkalosis. If the arterial CO_2 content is elevated and the pH is decreased this indicates that the lungs can no longer eliminate CO_2 adequately and respiratory acidosis has occurred. As the blood

An extrapleural pneumothorax on the other hand will cause only a slight impairment of the function compared to an intrapleural pneumothorax. After a lobectomy about one-third of the total function will remain on the operated side. A segmental resection may not cause a significant decrease of pulmonary function. Decortication may improve the pulmonary function considerably.

Ventilation.—There has been a certain confusion regarding the terminology of the lung volume and its various subdivisions. A committee of respiratory physiologists has agreed upon the following terminology and definitions. See Fig. 4.

Vital capacity is the maximal volume of gas that can be expelled from the lungs by forceful effort following a maximal inspiration. This is the oldest lung function test. Volume is measured unrelated to time. It is an adequate measure of ventilation only if the outflow of air from the lungs is unimpeded. There is no correlation of vital capacity to emphysema or bronchial obstruction. The patient may have oxygenating insufficiency and a normal vital capacity. It is important to eliminate such an unsuitable test. A much more valuable test of ventilation is the maximum breathing capacity where volume per unit of time is measured.

Maximum breathing capacity is defined as the maximum volume of gas that can be breathed per minute. Usually the expiratory air during a 15 second period is measured. The best result is obtained at a respiration of between 40 to 70 per minute. Normal values for the maximal breathing capacity (MBC) vary somewhat in different laboratories with the resistance to breathing in the different spirometers used. In our laboratory healthy individuals from 14 to 62 years of age (mean 28.3 years) showed the following values (see Table X).

TABLE X. NORMAL VALUES FOR MAXIMAL BREATHING CAPACITY (MBC). AGED 14 TO 62

	NO.	MEAN	S.D.	RANGE
MBC men	18	127 ± 7.5	31.8	80-188 L./min.
MBC women	11	102 ± 4.9	16.2	82-130 L./min.

Healthy men between 50 to 70 years of age have a MBC of 60 to 140 liters per minute (mean 90) and healthy women in this older age group have an MBC of 50 to 100 liters per minute (mean 73.5) (Comroe).

MBC is usually low in cases with emphysema due to the diminished elasticity and due to the extreme inspiratory position of the chest. If the MBC is compared to the arterial oxygen tension at rest a significant correlation is found in men (82 men, corr. coeff. 0.62 ± 0.07 $P < 0.001$) as well as in women (52 women, corr. coeff. 0.60 ± 0.086 , $P < 0.001$). See Fig. 5.

If then the arterial oxygen tension in men with MBC > 95 liters per minute is compared to the arterial oxygen tension in men with MBC < 56 liters per minute a statistically significant decrease is found in the later group, see Table XI.

If bronchspirometry is performed in the lateral position the oxygen uptake for the lower lung is increased. This is probably due to an increased blood flow through the lower lung and as well to an increased ventilation of the lower lung. This increased ventilation of the lower lung is due to the high position in the thorax of the lower diaphragm which has an extreme expiratory position facilitating a big inspiratory excursion.

This finding is constant and may be used as a function test (Steinman). If the diseased lung during bronchspirometry does not increase its oxygen uptake when the patient is in a lateral position with the diseased lung lowermost, this is considered to show a very small reserve function of the lung.

It is difficult to draw any conclusion from the absolute value of a lung's oxygen uptake per minute during bronchspirometry as the cardiac output may increase up to 50 per cent during the examination.

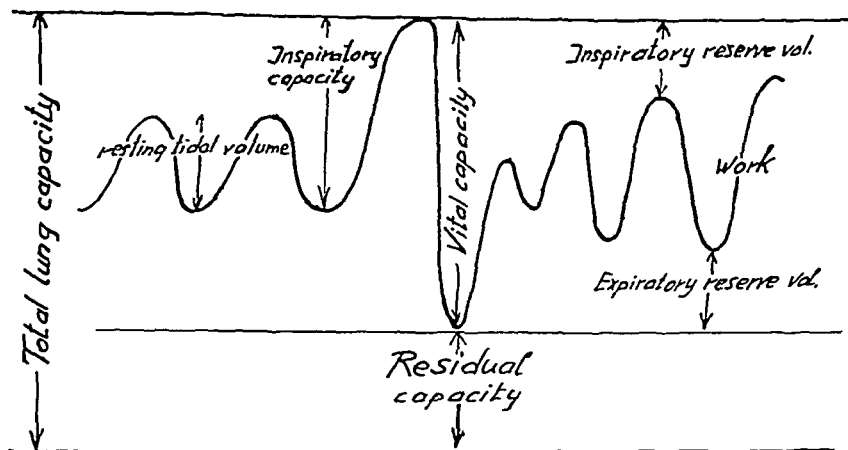


Fig. 4.—The terminology of the lung volume and its various subdivisions.

Bronchspirometry during effort has been studied by Björkman and Carlens. No further information is to be gained by this investigation as the share of the oxygen uptake by both lungs is the same at rest and during effort.

Changes in the pulmonary parenchyma and the bronchi as well as changes of the pleura decrease the function. In cases of unilateral parenchymal disease it is mainly the oxygen uptake which is diminished. In these cases the ventilation is never decreased to the same degree as the oxygen uptake. It may be possible to find cases with a pronounced decrease of the oxygen uptake of one lung at the same time that the ventilation is normal.

Bronchspirometry is the only method for studying the change in function of the operated lung and the compensatory change of the contralateral lung.

Through bronchspirometric investigations we have found a tremendous loss of function due to pleural disease. When an intrapleural pneumothorax is abandoned the re-expansion is often slight; it is mainly a shift of the mediastinum, an elevation of the diaphragm, and narrowing of the ribs that diminishes the pneumothorax space.

without any value. In this ratio only the MBC will show any variation. The test will therefore give no further information apart from the MBC. In an investigation of seventy-three patients no correlation was found between the arterial oxygen tension and the ratio minute ventilation at rest/MBC, see Fig. 6.

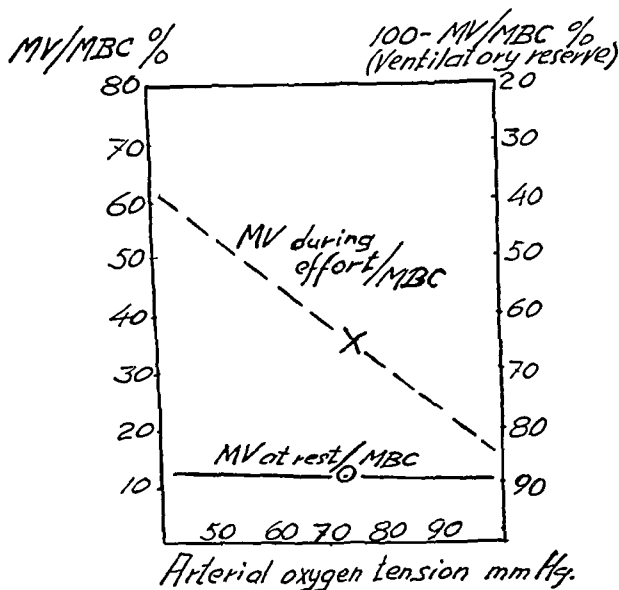


Fig. 6.—No correlation is found between the arterial oxygen tension and the ratio minute ventilation (MV) at rest/maximum breathing capacity. On the other hand a significant correlation is found : : : : : oxygen tension at rest and the ratio minute ventilation during effort/m : : : : : capacity.

In spite of a sincere desire to diminish the amount of pulmonary function tests we have introduced a new term, *ventilatory reserve*, calculated from the minute ventilation during effort (300 kilogram per minute on a bicycle ergometer). Ventilatory reserve = $100 - \frac{\text{Minute ventilation during effort} \times 100}{\text{MBC}}$

The ventilatory reserve was calculated from nineteen healthy individuals to $77 \pm 1.4 = \text{S.D.} = 6.2$; range = 86.5 to 65.5 per cent. Ventilatory reserve of less than 55 per cent is considered pathologic. The correlation between the ventilatory reserve and the MBC in men is good and the following values were obtained, see Table XII. The correlation between the arterial oxygen tension and the ventilatory reserve is also good. See Fig. 5, which shows the regression equation.

TABLE XII. COMPARISON OF VENTILATORY RESERVE ($100 - \text{MV EFFORT/MBC}$) AND ARTERIAL OXYGEN TENSION IN MEN WITH HIGH AND LOW MBC

MEN	NO.	100-MV EFFORT/MBC	NO.	pO ₂ MM. HG
MBC > 95 L./min.	23	$77 \pm 3.0\%$	25	79.1 ± 1.6
MBC < 56 L./min.	17	$41.4 \pm 4.9\%$	19	65.1 ± 2.3
Difference		36.6 ± 5.7		14.0 ± 2.8
		$P < 0.001$		$P < 0.001$

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Thus a significant correlation between the MBC and the oxygenating function of the lungs has been found. These findings demonstrate the importance of MBC as a lung function test.

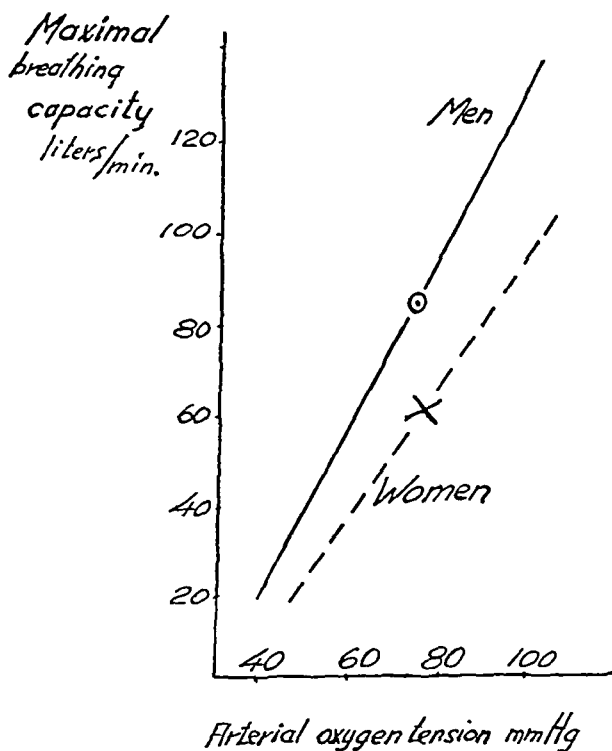


Fig. 5.—A significant correlation is found between the maximal breathing capacity and the arterial oxygen tension at rest.

Ventilatory reserve has earlier been defined as MBC minus minute ventilation at rest (Cournaud and Richards). The breathing reserve index is:

$$\frac{\text{MBC} - \text{minute ventilation at rest}}{\text{MBC}} \times 100.$$

Ornstein and his associates have calculated the breathing reserve from the ratio $\frac{\text{MBC}}{\text{minute ventilation at rest}}$. Only Warring has earlier correlated the minute ventilation during walking to MBC as an expression for the breathing reserve.

It is, however, evident that the minute ventilation during rest is fairly constant; either the ventilation is good or bad. Therefore, these calculations of the breathing reserve in which the minute ventilation at rest is used are

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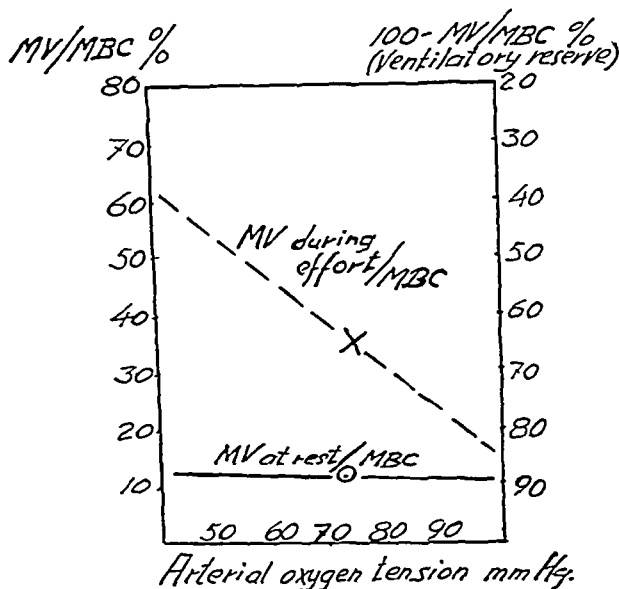


Fig. 6.—No correlation is found between the arterial oxygen tension and the ratio minute ventilation (MV) at rest/maximum breathing capacity. On the other hand a significant correlation is found between the arterial oxygen tension at rest and the ratio minute ventilation during effort/maximum breathing capacity.

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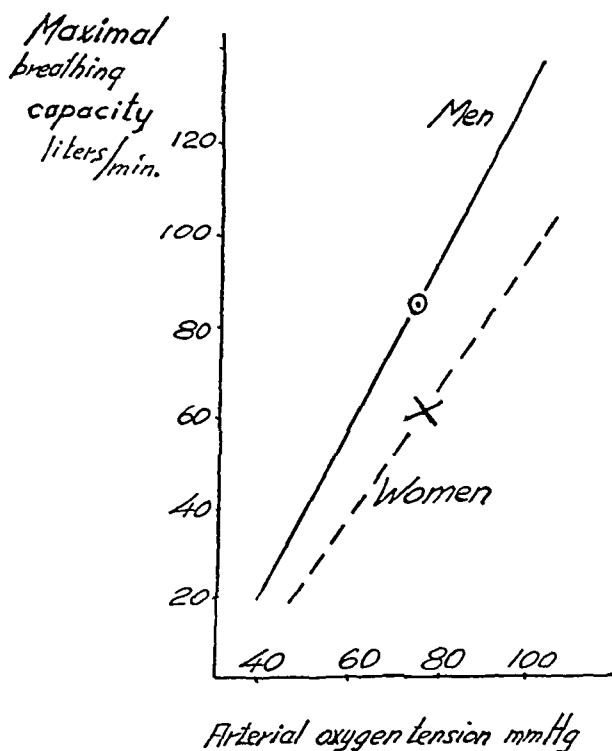


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The Pulmonary Circulation.—In the pulmonary circulation the vascular resistance is relatively low at a high flow. The circulation time is, therefore, short. It will only take about two seconds for blood from the right ventricle to reach the pulmonary capillaries and about the same time to return to the left auricle. At rest the blood is passing the pulmonary capillaries in three-fourths of one second and during effort in only one-third of a second (Roughton, 1945).

The pulmonary arterial resistance is calculated in units:

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 . Normally the pulmonary capillary pressure is less than one-half the capillary pressure in the systemic circulation. Therefore, a considerable safety margin against pulmonary edema exists.

In advanced cases of pulmonary disease emphysema and pulmonary fibrosis may cause a right heart failure, also called "cor pulmonale." It has been assumed that the destruction of the pulmonary capillaries in the lung should be the cause of the increased vascular resistance. If this were the case, the pulmonary capillary pressure should increase as well. In eighteen cases with pronounced pulmonary emphysema and fibrosis, however, Dexter found a normal pulmonary capillary pressure in spite of an increased pulmonary arterial pressure. The arteriolar resistance in the lung could be increased up to more than twenty times the normal value. In cases with an increased pulmonary arteriolar resistance a decreased cardiac output and an increased arteriovenous oxygen difference was found. The impairment of circulation in cases with advanced pulmonary disease is, therefore, considered to be related to the resistance to blood flow through the pulmonary arteriole (Dexter). On the other hand, Dexter did not find any correlation with the pulmonary arteriolar resistance and the maximal breathing capacity, the vital capacity, and the residual air.

In cases with chronic diseases causing a considerable reduction of the vascular bed and an increased pulmonary arterial pressure with a low cardiac output the prognosis is considered poor. In healthy individuals Courmand and his co-workers consider the cardiac output at rest may increase up to more than three times this value without any significant increase in pulmonary arterial pressure. Due to this big margin the pulmonary arterial pressure is found to be within normal limits in spite of a very advanced pulmonary disease.

Residual Air.—The residual capacity is the volume of gas remaining in the lungs at the end of a maximal expiration. Values of more than 35 per cent of the total lung volume are considered pathologic (Birath). In normal cases the values are reliable and duplicate residual air values often check within 3 per cent. In patients with emphysema and an uneven intrapulmonary mixing the method is less precise. An increased residual capacity is caused by hyperinflation of the lung and may be due to: (1) true emphysema, tearing of the alveolar septa, and reduction in pulmonary capillary bed; (2) obstruction to the airway, that is asthma; (3) compensatory overinflation of the lung following resection of lung tissue; (4) deformity of the thorax; (5) decreased elasticity of the lung in the older age group; (6) fibrosis and congestive heart failure.

In our cases with increased residual capacity we have found a decreased arterial oxygen tension (oxygenating insufficiency) and a decreased ventilatory reserve (ventilatory insufficiency).

An uneven distribution of the respiratory air with underventilation of the alveoli and hyperventilation of others may, depending upon the distribution of the pulmonary capillary blood flow lead to an oxygenating insufficiency. A comparably simple test of the intrapulmonary gas mixing has been devised by Cournand and his co-workers. The patient breathes oxygen for seven minutes and at the end of this period an alveolar gas sample is analyzed for nitrogen concentration which in normal cases may not exceed 2.5 per cent nitrogen. If the inspired oxygen is evenly distributed to all alveoli a very small amount of nitrogen remains after seven minutes. On the other hand, in badly ventilated alveoli the nitrogen concentration remains high and will show an abnormally high value of nitrogen in the final alveolar sample after seven minutes. This test is influenced by the lung volume, the effective tidal volume, and the frequency of breathing as well as by the distribution factor.

In cases with a small minute ventilation, too high a value may be obtained. On the other hand, a too low value may be obtained in cases with a pronounced emphysema due to hyperventilation. This shows the limitation of the method.

A more sensitive method is to use a rapid gas analyzer such as the nitrogen meter. In a group of patients 78 per cent were found to have an abnormal intrapulmonary mixing by this sensitive method compared to only 32 per cent when the Cournand test was used (Courroc and Fowler).

By bronchospirometry the determination of ventilation of each lung separately is determined. The determination of the maximal diaphragmatical movements will also give certain information of the ventilation of each lung.

Diffusion.—Oxygen is going from the alveolus with a high pO_2 through the alveolar membrane to the capillary where pO_2 is lower. The difference in pO_2 on each side of the alveolar membrane is less than 12 mm. Hg (Cournand and his associates). In these determinations blood from the brachial artery has been used. It is, however, necessary to realize that some of the bronchial veins drain into the pulmonary veins thus decreasing pO_2 in the arterial blood.

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function. If an operation is performed on the best lung the patient is forced to ventilate the remaining lung parenchyma on the side of operation well enough to prevent an atelectasis. As an area of the lung with no or minimal function is resected the chances to stand an operation on the lung with the better function are very good.

Bronchspirometry should not be performed in tuberculous cases with big cavities and considerable expectoration. In cases with tuberculosis the bronchspirometry should, if possible, be performed in connection with the operation. In these cases we always use Carlens double lumen catheter for endobronchial anesthesia in order to prevent spillover. When the tube is introduced we perform the bronchspirometry immediately on the operating table and then continue with the resection.

7. The most physiologic way to determine if the patient will withstand a pneumonectomy is the occlusion of the pulmonary artery according to Carlens, Hanson, and Nordenström. This investigation is of value in cases where the remaining lung has an impaired function.

8. Pressure measurements in the pulmonary artery are of no help in determining the immediate operative risks. These investigations may, however, be of prognostic value.

We have yet a lot to learn about pulmonary function. It is our intention to use few but adequate function tests. We believe that with the aid of our present pulmonary function tests we may determine if a patient can withstand an operation or not, but we do not yet know the value of our function tests in regard to the future prognosis for the patient.

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LEIOMYOMA OF THE ESOPHAGUS

REPORT OF A CASE WITH SUCCESSFUL ENUCLEATION OF THE TUMOR

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TUMORS of the esophagus may be divided into those which are malignant and those which are benign. While the prognosis for malignant tumors is extremely bad, most of the literature has concerned itself with detailed descriptions of the anatomy, microscopic pathology, and surgical treatment of carcinoma of the esophagus. Benign tumors of the esophagus, on the other hand, are infrequent enough so that whenever a case is found either at the operating table or at the post-mortem examination it usually reaches the literature. In spite of this fact, when Garlick and Stegmaier summarized the literature up to January, 1951 there were less than twenty cases of benign tumors of the esophagus, and in most of these the lesion had been discovered at autopsy. In May, 1951, Myers and Bradshaw³ reported that they were able to find only 39 surgically treated benign intramural tumors of the esophagus; to these they added three of their own. We have found two additional cases reported since that time.^{2, 4} This paper adds still another case to those already reported; it is a case in which the tumor was diagnosed preoperatively and the lesion was successfully removed surgically.

CASE REPORT

S. R., a 37-year-old white woman, was first seen by one of us (S. O. K.) in 1948. At this time she complained of vague indigestion, right upper quadrant and epigastric pain, "bloating" shortly after meals, and some intolerance to fatty and fried foods. Most of these symptoms were of recent onset. The postprandial bloating had existed for at least ten years. The initial physical examination was normal except for a mild hypotension and the presence of a right lower quadrant appendectomy scar.

Electrocardiogram, blood count, and urinalysis were entirely normal. Fluoroscopic examination of the chest revealed no abnormal pulmonary or cardiac shadows. A barium swallow revealed some spasm at the distal end of the esophagus. No films of the esophagus were taken at this time. An oral cholecystogram demonstrated a poorly functioning gall bladder with many small radiopaque stones floating at a uniform level. In view of these findings, in December, 1948, a cholecystectomy was performed from which the patient made an uneventful recovery.

About one year following the cholecystectomy the patient began to complain once again of bloating shortly following meals. In addition there was also a sensation of giddiness, vertigo, and constipation. It was felt that many of these symptoms were due to a state of mild anxiety, and treatment was ordered in that direction. The symptoms remained about the same and once again a barium swallow and fluoroscopic examination revealed some spasm at the lower end of the esophagus. However, at this time there appeared to be some distortion of the normal pattern.

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The patient was admitted to the Albert Einstein Medical Center, Northern Division, for study. All studies other than those related to the esophagus were within normal limits. The roentgenologist interpreted the x-ray films as showing either a mediastinal mass encroaching upon the esophagus or an intramural esophageal tumor (Fig. 1). A slight hiatal hernia was also present. The patient refused esophagoscopy and was discharged, taking a mild antispasmodic and a fairly normal diet.



Fig. 1.—X-ray view of the lower esophagus taken in November, 1950, showing the deformity produced by the lesion.

Since the patient was very apprehensive about any operative procedure, it was decided to re-examine the esophagus roentgenologically at regular intervals. Two successive series of films failed to show any change in the contour or size of the mass (Fig. 2). Although the patient's symptoms were fairly well controlled by antispasmodics, episodes of nausea, bloating, and even vomiting occurred, particularly when she was under any emotional stress. In view of the fact that the latter group of symptoms appeared to increase in severity surgical intervention was again recommended and on Nov. 27, 1951, she was admitted to the hospital for operation.

Operation was performed on Nov. 29, 1951. With the patient under endotracheal anesthesia the left thoracic cavity was entered through a posterolateral incision, removing the eighth rib from the costal margin to the angle. Exploration of the mediastinum revealed a large tumor mass in the lower third of the esophagus, involving approximately two-thirds of the circumference of the organ. The mediastinal pleura over the lesion was incised and the esophagus mobilized. The outer wall of the esophagus over the lesion was incised and the tumor was completely enucleated without entering the lumen of the organ. While the outer muscular layer of the esophagus was somewhat attenuated producing a diverticular defect, it was felt inadvisable to resect any of this tissue. The wall was then reconstructed with several interrupted sutures of 00 chromic catgut, and the chest was closed in layers. A large catheter was placed in the pleural cavity for drainage.

The resected specimen consisted of a mass, irregular in shape, moderately soft in consistency, gray-white in color, beneath a thin transparent, fibrous, hemorrhagically discolored



Fig. 2.—X-ray film taken one year later showing no apparent change in the appearance of the lower esophagus.



Fig. 3.—Microscopic section of the lesion. There is no evidence of malignancy.

capsule. It measured 8 by 4 by 4 cm. Its cut surfaces were homogeneously gray-white and whorled. Microscopic examination revealed the lesion to be a benign leiomyoma (Fig. 3).*

The postoperative course was entirely uneventful. Oral feedings were started on the third day and rapidly increased, so that the patient was discharged on the tenth day on a bland diet. The intercostal catheter drained for twenty-four hours and was removed on the third postoperative day. There was a moderate pleural effusion in the left pleural cavity, but this absorbed before the patient left the hospital. At no time was there any difficulty in swallowing and at no time during the postoperative course did the patient vomit. The day before the patient left the hospital an x-ray film of the lower esophagus was made, so that we might have a baseline study of the anatomy and function of the organ. This was con-



Fig. 4—X-ray photograph taken immediately after operation showing the diverticular defect where the lesion had been removed.

sidered especially important in view of the marked redundancy of the wall following the enucleation of the tumor. The x-ray pictures made at this time showed no obstruction. There was a slight redundancy of the distal esophagus with the formation of a small dependent pouch in which a small amount of barium collected (Fig. 4). Since the time of the operation the patient has done well, although on many occasions, especially when under severe emotional stress, she does develop symptoms very similar to those of which she complained before the operation. Most of those symptoms are controlled by tincture of belladonna after meals. One year later another x-ray study of the lower esophagus demonstrated no significant change (Fig. 5).

*Report by Dr. Henry Brody.

Comment.—It is obvious from the above case study that many difficulties were encountered in finally establishing a definite diagnosis. The original diagnosis of calculous cholecystitis was a deterrent in arriving at our ultimate diagnosis. The patient had symptoms and signs pointing to gall bladder disease for which a cholecystectomy was done in 1948. Following this operation certain symptoms persisted. These might lead one to suspect the diagnosis of a postcholecystectomy syndrome. One symptom, present preoperatively and persisting during the postcholecystectomy course, was the sensation of early bloating following a heavy meal. In spite of the fact that this sensation occurred primarily after emotional stress, it was felt that some organic cause might be responsible. In addition, there was some upper epigastric distress with pain radiating over the substernal area. The diagnosis of coronary artery disease was excluded by a cardiac survey. The ultimate diagnosis rested upon the x-ray examination. This consisted of a series of carefully interpreted x-ray films of the lower esophagus.



Fig 5—X-ray picture taken one year later showing no apparent change from Fig 4.

Surgical intervention was advised as soon as the diagnosis of a tumor in the region of the lower end of the esophagus was made. Because of the anxiety state that existed throughout the ensuing time and because of the patient's marked apprehension concerning any surgical intervention, the operation was delayed until that time when symptoms became progressively worse. At such an opportune moment, surgery was once again recommended and the patient proved amenable to this suggestion. At the time when the patient gave consent to operation she was carefully admonished that, in spite of the fact that operation was indicated to remove a definitely visualized tumor, no guarantee could be given her that all symptoms would be eliminated by such an operation.

At the time of exploration it appeared that we were dealing with a well-circumscribed tumor of the lower esophagus. It is generally accepted that wherever possible these lesions, if they are intramural, should be enucleated. To subject these patients routinely to segmental resection of the esophagus would of necessity expose these patients postoperatively to all the undesirable sequelae of any such resection. Therefore, the lesion was exposed by a longitudinal incision through the outer muscular coat. The lesion was then demonstrated as being intramural, and with finger dissection it was possible to completely enucleate it without entering the esophageal lumen. This was so in spite of the fact that the tumor almost completely involved the entire circumference of the esophagus. After the lesion had been removed it was obvious that there was a marked attenuation of the layers of the esophagus external to the mucosa. It was felt unwise to attempt any sort of plastic repair at this time, since such a procedure might produce marked distortion of the lower end of the esophagus. It was felt that the mucosa would probably accommodate itself to this attenuated muscular layer and in this way obliterate the dead space which was present immediately after operation between the mucosal and extramucosal layers. It was considered unlikely that the muscular layer would shrink down to its original size. Follow-up x-ray films have confirmed our impressions, and while there is obviously a diverticular type of deformity, it in no way produces any obstruction and it empties normally. The fact that there has been no apparent increase in the size of the defect after one year leads us to believe that there will probably not be any increase over the next few years at least. Should the diverticular deformity enlarge and then produce symptoms, it may become necessary to perform some operative procedure on this portion of the esophagus. However, it is our conviction that even if this procedure can be put off for five, ten, or more years the patient is much better off with the deformity that is present than she would be with an esophagogastrostomy. The prognosis for this case, as far as the lesion itself is concerned, is good. Careful microscopic examination of the tumor reveals it to be entirely benign. In view of the fact that the lesion was entirely removed, there is no opportunity for recurrence. On the other hand, symptoms have continued, although to a much milder degree, since the operation. These symptoms are probably more on a functional basis than an organic one. There is no reason for us to believe that these symptoms will change.

DISCUSSION

Benign intramural tumors of the esophagus are usually solitary. Myers and Bradshaw in their review of operated cases found only one in which more than one lesion was present. Most of these tumors occur in the lower third and the majority are leiomyomas. The distribution by sex is almost identical, and the ages of the patients in the literature range from 19 months to 66 years. These lesions usually go unrecognized for many years because of the absence of symptoms. When they become large enough they may produce obstruction or bleeding if the overlying mucosa undergoes necrosis from pressure or

ischemia. In thirty of the forty-two cases reported by Myers and Bradshaw, simple enucleation was done with apparent cure of the lesion. However, in ten cases either esophageal resection or mucosal resection was necessary in order to completely remove the tumor.

The prognosis for these benign lesions of the esophagus, as is true of benign lesions of other parts of the body, is good. When microscopic examination of the lesion after removal reveals that there is no evidence of malignant change, then there is little reason to suspect that there should be any recurrence following total removal. It is well to remember that any one of these tumors while they may appear to be entirely encapsulated and completely benign grossly, may show microscopic evidence of malignancy. The prognosis in those cases is the same as for sarcomas in other portions of the body, the anticipated five-year survival being dependent upon the particular type of sarcoma present. It is not in the province of this paper to philosophize upon the theoretical prognosis of any one of these lesions should they show any malignant change, but it suffices to say that malignant tumors of the esophagus other than carcinomas are extremely rare.

SUMMARY

The case report of a patient in whom an intramural leiomyoma of the esophagus was successfully removed is reported. A brief review of the recent literature is presented.

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GIANT INTRAMURAL LEIOMYOMA OF ESOPHAGUS

A CASE REPORT

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THE case presented here is of interest because it concerns a tumor that is encountered very infrequently, and, in this particular instance the lesion had attained such a great size that its surgical management necessitated an operative procedure of unusual magnitude. This patient was under continuous medical supervision from 1940 until 1952, during which time the esophageal leiomyoma was regarded as a diaphragmatic hernia with a congenitally short esophagus. At the time of surgical resection, a bilateral thoracotomy and an extensive esophagogastrectomy were required to remove the tumor.

CASE REPORT

K. C., Case 315315, was a 17-year-old boy who was admitted to the hospital on May 2, 1952, complaining of dysphagia and the regurgitation of blood. Since the age of 6 he had experienced difficulty in swallowing, and throughout his entire life he had been under constant medical care for this and other complaints. At an early age bilateral congenital cataracts were extracted. He suffered from a congenital hearing impairment and he was required to wear an artificial hearing aid. He had a congenital prolapse of the rectum. Of all difficulties the most annoying to him personally was the inability to eat normally. Because of his multiple handicaps his parents sent him to private boarding schools, and the preparation and ingestion of his food was a ritual that set him apart from his fellow classmates.

The problem of the dysphagia had been studied and treated since the age of 6 both here and at several other larger medical centers throughout the country. X-ray studies (Fig. 1) of the esophagus demonstrated a bizarre picture. The upper esophagus was dilated. The lower half of the esophagus was distorted into a configuration that led to a diagnosis of "congenital shortening of the esophagus with diaphragmatic hernia, stricture, and cardiospasm." These diagnoses were made at more than one medical center and the recommended treatment was always the same, endoscopic dilatation. These procedures were carried out innumerable times from 1940 through 1951 and gave the patient temporary partial relief of the esophageal obstruction. Esophagoscopy had been done on more than one occasion and had shown the esophagus to be narrowed at the mid-esophageal level so that the instrument could not be advanced beyond this point. The mucosa was normal and no tumor was ever visualized.

At the time of this admission diagnostic studies were repeated, and a barium examination of the esophagus was similar to that obtained in 1948. The boy had grown and the structures were larger but the basic picture was unchanged. One border of the tumor can actually be made out just to the left of the midline (Fig. 2). Shortly after this present admission to the hospital the boy's esophagus became completely obstructed. Even water taken by mouth would be regurgitated a few minutes after being swallowed. Repeated attempts were made to introduce a tube into the stomach for alimentation but all were unsuccessful. Efforts were made to pass a string attached to a mercury weighted balloon in order to dilate the area of stricture but this too met with failure as the mercury bag would not drop beyond the mid-esophageal level.

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Operative intervention became mandatory for the maintenance of nutrition, and I elected to make an effort to correct the area of stricture which was believed to be at the point where the thoracic stomach joined the shortened esophagus. On May 24, 1952, a right thoracotomy through the eighth interspace was carried out under endotracheal anesthesia, and upon exploration a large tumor mass was found on the surface of the right diaphragm. It ran obliquely from the lateral chest wall and extended across the mediastinum into the left hemithorax. A tremendously dilated segment of the esophagus entered the surface of the mass from its most superior aspect, and it was soon realized and confirmed by biopsy and frozen section diagnosis that we were dealing with a leiomyoma of the esophagus. The tumor was attached to all contiguous structures with vascular adhesions. These were divided and the mass mobilized as completely as it was possible from



Fig. 1.—Photograph of one of the early esophagrams (Sept. 11, 1948). The tumor mass could not be visualized on the x-ray pictures at this time.

the right-sided approach. The esophagus itself was freed for a considerable distance but subsequently it was found that the dissection of the esophagus should have been carried up much further from the right side. The right thoracotomy incision was then closed, the patient turned, and the operation continued by opening the left hemithorax through the seventh intercostal space. The leiomyoma was then delivered into the left side and the situation evaluated in regard to the extent of resection.

The inferior portion of the tumor constituted its largest diameter and the huge bulbous end extended below the diaphragm. The superior end of the tumor lay just below the aortic arch. The upper end of the esophagus was transected where it entered the tumor, and it was noted in the cut section that the leiomyomatous tissue invaded the wall of the esophagus above the level of the actual tumor mass. It was evident at this time



Fig. 2.—This demonstrates the appearance of the esophagus at the time of the present admission (May 17, 1952). The barium pattern above the right diaphragm was regarded as representing rugal folds of the stomach.

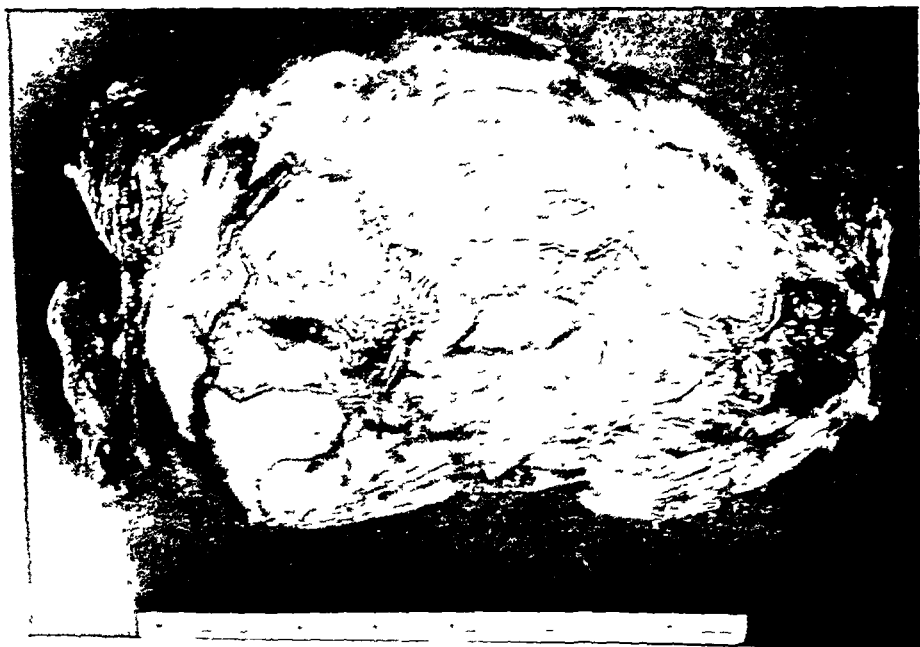


Fig. 3.—Photograph of resected tumor. The upper esophageal end is on the right and the lower gastric end on the left.

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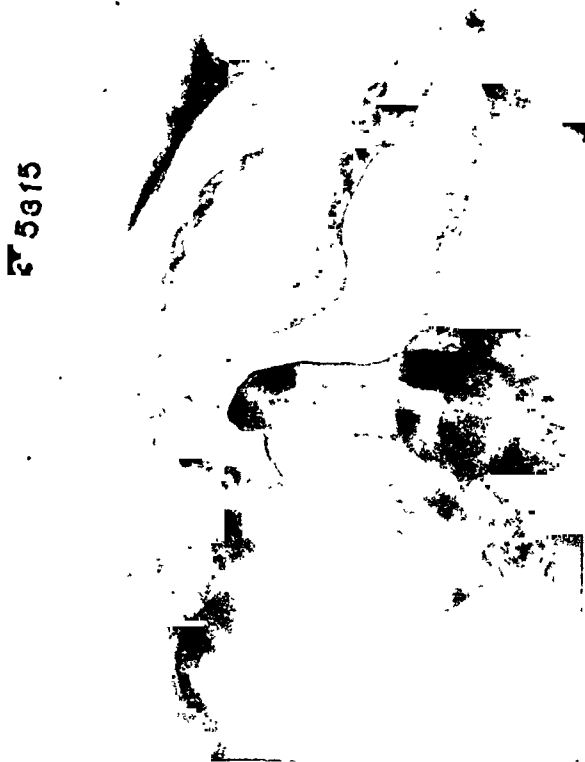


Fig. 1.—Photograph of one of the early esophagograms (Sept. 11, 1948). The tumor mass could not be visualized on the x-ray pictures at this time.

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worse in the patient's condition and it became apparent that he had ruptured the esophago-gastric anastomosis and had developed an acute mediastinitis and left empyema. An intercostal tube was inserted into the left chest, and within a few hours 5,000 c.c. of fluid had drained out. Recovery from this point on was relatively uncomplicated.

An attempt was made to treat the esophagopleural cutaneous fistula by feeding the patient through a gastric tube placed in the stomach but this was unsuccessful because a large proportion of the formula would be regurgitated out of the stomach into the fistula.



Fig. 4.—Postoperative esophagram. The upper segment of the esophagus remains dilated.

The method of jejunal alimentation described by Fallis and Barron² of this hospital was then instituted. A small intranasal polyethylene tube was passed into the upper portion of the jejunum and a whole liquefied food formula pumped mechanically through the tube into the jejunum. This feeding technique was completely successful in maintaining nutrition and was continued for forty-two days at which time the fistula closed. A small drainage tube was then slowly withdrawn from the residual fistulous tract over a period of one month with eventual complete healing.

At present (nine months later) the patient is completely free of any swallowing difficulties. Postoperative esophagrams (Fig. 4), taken four months after operation, show a satisfactory result. The upper esophagus is still dilated but there is no delay in the passage of barium through the anastomosis into the thoracic stomach.

DISCUSSION

In recent years several authors have pointed out the rarity with which benign tumors of the esophagus are encountered. In an article published in

that the aortic arch had to be mobilized and the esophagus again divided at a much higher level. Before proceeding with the dissection at the diaphragmatic end, the tumor had to be partially returned to the right chest because it filled the wound and mitigated against any further technical steps. The diaphragm was then incised and the mass found to envelop the upper third of the stomach.

The operation continued and as a preliminary step to resecting the involved portion of stomach, a splenectomy was carried out. The omentum was detached from the greater curvature of the stomach and access gained to the lesser omental cavity. Here, the left gastric artery was isolated and divided between ligatures. The upper end of the gastro-hepatic ligament and the attachments of the tumor mass to the diaphragm were cut between clamps and the tumor could then be removed (Fig. 3). The incision in the stomach was closed so as to form an elongated tube that easily reached above the aortic arch without tension. Attention was then directed to mobilizing the aortic arch. Three sets of intercostals and a bronchial artery were divided, and the aorta was retracted anteriorly. The esophagus was delivered above the arch and an additional 9 cm. of this organ was removed. The cut section at this level showed the muscle layers to be free of tumor tissue, although the wall itself was markedly thickened and edematous. The tissue was of such poor quality that it could be crushed between thumb and forefinger. However, a perfectly tight two layer anastomosis was carried out between the stomach and esophagus. The anastomotic line was placed anterior to the arch and a few inches above it.

The incision in the diaphragm was closed with interrupted sutures and the edge of the new hiatus sutured to the thoracic stomach. A gaping hole was present in the mediastinum, the site from where the tumor had been resected, and a single thoracotomy tube was placed so as to drain both sides of the chest. The left-sided wound was closed and the operation terminated. The total operating time was nine hours. During the course of the procedure the patient was supported with 2,500 c.c. of whole blood and 1,000 c.c. of isotonic saline.

Pathologic examination was carried out in the Department of Laboratories, Henry Ford Hospital, under the direction of Dr. Frank Hartman and was reported, in part, as follows:

"Specimens consists of a large tumor mass, a spleen and portions of stomach and esophagus. The large tumor weighs 1,420 grams and has previously been opened. In the opened condition it measured 19 cm. in length, 15 cm. in width and 7 cm. in thickness."

Microscopically the "tumor is composed entirely of elongated, fusiform, pink staining cells arranged in interlacing longitudinal groups. The nuclei are oval and present very little pleomorphism. The pink-staining cytoplasm is in abundance. This presents a typical picture of leiomyoma."

The patient's life hung in the balance during the first three postoperative days because of extreme respiratory difficulties. He was in an oxygen tent and, in addition, was given supplementary oxygen through a nasal catheter. But even under these conditions he manifested a slight tinge of cyanosis. Any factor that compromised the patient's slender margin of respiratory reserve required prompt attention. A few hundred cubic centimeters of fluid aspirated from one side of the chest or the other would tide him over a period when he was developing respiratory failure. He had considerable bronchial secretion which he was unable to raise efficiently and frequent tracheal aspirations were done to clear the airway. On one occasion a bedside aspiration bronchoscopy was carried out. On the second postoperative day he developed a gastric dilatation which compressed the left lung and resulted in a critical hypoxic state. A gastric tube was passed with prompt alleviation of the dyspnea.

He survived this difficult period and by the end of the first postoperative week he was improving rapidly. Dyspnea was controlled with a small volume of nasal oxygen. A liquid diet was instituted on the fifth postoperative day and was progressively increased with no ill effects. On the eighth postoperative day there was a marked change for the

The first problem was the necessity of carrying out a bilateral thoracotomy in one consecutive operative procedure. Study of Figs. 5 and 6 will illustrate why exposure from both right and left sides of the chest was mandatory in the technical management of this case. The bulk of the tumor mass was situated in the right hemithorax, but its largest end was on the left side and it descended into the left upper quadrant of the abdomen. A supplementary abdominal incision would not have provided adequate exposure. Consequently we were forced to open the left side and incise the diaphragm for proper visualization in this area. Chi and Adams² opened both sides of the chest in their patient, but the two thoracotomies were separated by a month's interval.

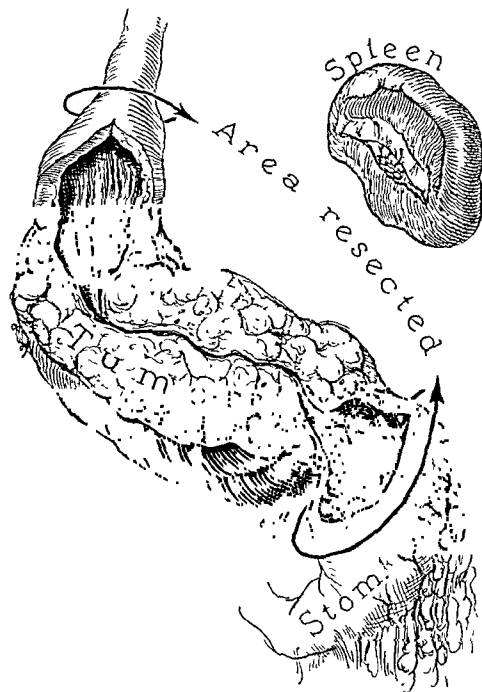


Fig. 6.—Cross-sectional drawing showing the extent of surgical resection.

I was aware of Overholt's⁵ experience, where, in three instances, simultaneous bilateral thoracotomies had been done. Encouraged by these previous successes, the decision was made to proceed with the operation from this standpoint.

Overholt's patients experienced no serious problem in their postoperative physiologic adjustment to simultaneous bilateral thoracotomy. In the case presented, the physiologic respiratory insult was extremely marked. The patient survived only because the stamina of youth was in his favor and because of the diligent care given by the surgical residents. The duration of the operation, the fact that the thoracotomies were consecutive and not simultaneous, and the extensive surgical resection that was required undoubtedly accounts for the severe postoperative reaction in this patient.

1950 Chi and Adams² tabulated the benign esophageal tumors that had been treated surgically and reported in the medical literature. These were of all types and totaled only twenty at that time. Their article also contains an excellent bibliography on this subject.

In the majority of the cases cited, the lesions were of the mucosal pedunculated type or else they were localized intramural myomas that could be enucleated from the esophageal wall without interrupting the continuity of the organ. There are only three instances recorded in the medical literature where



Fig. 5 —Artist's diagrammatic reconstruction of the esophageal leiomyoma in situ illustrating the relations of the tumor

intramural leiomyomas of the esophagus were successfully treated by a radical esophagectomy and reparative esophagogastrostomy. Broch³ (1942), Kenworthy and Welch⁴ (1948), and Chi and Adams² (1950) described cases that required an extensive surgical resection. In Broch and Kenworthy's cases the leiomyomas involved the esophagogastric junction. The patient operated upon by Chi and Adams had a leiomyoma in the upper third of the esophagus. In the case described here, the tumor involved the lower two-thirds of the esophagus proper, including the cardia and the upper third of the stomach.

A correct preoperative diagnosis was not made in this case and the decisions regarding management had to be made at the operating table. Two problems were immediately considered after the true nature of the pathology was ascertained and before the mobilization of the tumor was begun.

INTRATHORACIC MENINGOCELE NOT ASSOCIATED WITH NEUROFIBROMATOSIS

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INTRATHORACIC meningoceles are of sufficient rarity to warrant the presentation of individual cases. Only fourteen proved cases could be found in the literature at this time. The following case, we believe, is the fifteenth proved case and the fourth case not associated with neurofibromatosis.

CASE REPORT

A 29-year-old Negro woman (gravida iii, para i) was seen in the emergency room on April 4, 1952; she complained of dysmenorrhea and menorrhagia. A chest film revealed a large intrathoracic mass, apparently unassociated with these symptoms. She was referred to chest clinic but failed to keep the the appointment. Two months later she was readmitted to the hospital with the same essential complaints, was treated, and then transferred to the chest service.

Past history and family history were noncontributory. Physical examination was essentially negative except for the presence of bilateral lower quadrant tenderness and a large midline mass extending almost to the umbilicus. A mass in the right uterine adnexa deformed the vaginal vault. These masses, surgically removed at a later date, were fibromyomas of the uterus. No evidence of neurofibromatosis was noted. The laboratory findings, including spinal fluid studies, were normal.

Chest films revealed a large, sharply circumscribed, homogeneous density filling the entire upper third of the left lung field (Fig. 1). The trachea was displaced slightly anteriorly, and the esophagus was displaced to the right. A scoliosis of the upper thoracic spine was present, with the concavity on the left side. No definite bone destruction was noted but there was thought to be pressure atrophy of the left first rib posteriorly. A lung cyst or neurofibroma was considered the most likely diagnosis by both the surgeons and radiologists.

Operation.—A thoracotomy was done on the left side through the bed of the fourth rib. A round, cystic tumor, approximately 10 cm. in diameter, was seen to fill the apex of the left chest. The pleura and the second intercostal nerve on the anterior surface of the tumor were dissected away, and approximately 150 c.c. of clear fluid was aspirated to facilitate removal of the tumor. Dissection was carried down to the second intervertebral foramen, through which the mass entered the chest, and the cyst was opened. The foramen was only slightly larger than normal, measuring approximately 7 or 8 mm. in diameter. Through the lumen of the cyst pedicle could be seen the dentate ligaments and spinal cord. At this point, it was evident that the cyst was actually a meningocele. The neck of the meningocele was closed with a purse string suture of 000 silk reinforced by interrupted sutures of No. 30 cotton. The suture line was covered with Gelfoam.

Postoperatively the patient drained a light amber fluid, thought to be spinal fluid, from the wound at the rate of 300 to 350 c.c. daily. By the third week this decreased to 125 c.c. daily, gradually diminishing thereafter until it finally ceased. The pleural drainage tubes were then removed with no reaccumulation of fluid. There was a slight weakness of the left arm and left leg which cleared within a few days. This was thought to have been due to arachnoiditis. A definite Horner syndrome was noted on the left. This was said to have been present to a lesser degree preoperatively though not recorded on the

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The second problem considered at the operating table was a definite deterrent to proceeding with the removal of the tumor. Because the esophagus above the mass was dilated and its wall was markedly edematous as a result of the chronic obstruction it was questionable whether a leak-proof gastro-esophageal anastomosis could be made. Even if this were accomplished it seemed doubtful whether or not tissue of this nature would heal. The opinion of Dr. Laurence S. Fallis, Surgeon-in-Chief at this hospital, was sought in this regard. He felt that there was no other acceptable alternative in the management of the case, except resection, and advised that the risk of carrying out the anastomosis should be assumed.

The anastomotic breakdown which occurred on the eighth postoperative day was not unexpected, and was diagnosed a few hours after it happened. Prompt drainage was instituted, massive doses of antibiotics started, and the patient recovered rapidly from the acute effects of the accident. Subsequent course was remarkable for the manner in which nutrition was maintained in the face of an esophageal fistula and a draining empyema. Throughout the forty-two day period, when nothing was administered by mouth, the patient lost only five pounds in weight. Dr. James Barron, of this hospital, managed this aspect of the case and he estimates that between 4,000 and 5,000 calories a day were pumped through the polyethylene tube into the jejunum.

SUMMARY

A case of esophageal leiomyoma is reported. This is believed to be the fourth such case recorded that survived a radical esophagectomy and esophagogastrostomy. It is thought to be the largest esophageal tumor (1,420 Gm.) ever resected surgically.

The method of jejunal alimentation which was used in the management of the esophagopleural-cutaneous fistula that developed in this patient was eminently successful in maintaining nutrition.

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chart. The patient was given penicillin and streptomycin prophylactically. Upon discontinuance of these drugs the patient's temperature rose to 102° F. and she developed a stiff neck, headache, and return of the weakness of the left leg. A lumbar puncture at this time revealed normal findings. Upon reinstitution of antibiotic therapy, the fever promptly abated and the meningeal signs and symptoms disappeared. The weakness of the left leg persisted, however. Two and one-half months following surgery the patient was able to walk without the aid of a cane but still exhibited a slight bilateral ankle clonus, hyperactive ankle jerk, and weakness of the hamstring group of muscles of the left leg.

A summary of all proved cases reported to date with an additional two cases not previously tabulated is presented below.

DISCUSSION

In reviewing the cases summarized in Table I the constancy of certain clinical features was striking. Ten of the fifteen cases had neurofibromatosis; all but one had definite vertebral abnormalities. These two findings in the presence of an intrathoracic mass, paucity of symptoms, neurologic or otherwise, should stimulate efforts to demonstrate a meningocele by myelography. In two of these cases the correct diagnosis was made prior to surgery, 2 and 6. The most frequent preoperative diagnosis was that of neurofibroma.

TABLE I. SUMMARY OF CASES PREVIOUSLY REPORTED*

AUTHOR	NO. OF CASES	TREATMENT	ASSOCIATED NEUROFIBROMAS	VERTEBRAL CHANGES
1. Pohl, ¹ 1933	1	Surgery; death from empyema	Yes	Yes
2. Schüller, ² 1938	1	Not resected; death following neurectomy	Yes	Yes
3. Ameuille, ³ 1940	1	Surgery; cyst packed; death from empyema	Yes	Yes
4. Welch, ⁴ 1949	1	Resection; good results	Yes	Yes
5. Byron, ⁵ 1949	3	One case resected with good results. One case treated conservatively. One case resected; the patient expired during surgery	Yes, two cases No, one case	Yes
6. Mendelsohn ⁵	1	Resection; good results	Yes	Yes
7. Head ⁵	1	Treated conservatively	?	?
8. Ciaglia ⁵	1	Resection; good results	Yes	Yes
9. Cross, ⁶ 1949	1	Treated conservatively	No	Yes
10. Kessel, ⁷ 1951	2	One case resected with good results. One case treated conservatively	Yes, both	Yes
11. Rubin, ⁸ 1952	1	An infant who expired before treatment was instituted.	No	Yes

*Campos⁹ in 1946 presented two cases with the above findings but the diagnosis was not definitely proved. In view of the frequency of the associated findings, they probably represented meningoceles.

The importance of the associated clinical features was pointed out by Rubin⁸ in a review of two separate series of intrathoracic neurogenic tumors. Only four cases of neurofibromatosis were found in a total of 135 cases. This is an important observation because in almost all of the cases presented here, the provisional diagnosis was that of neurofibroma.

No etiologic factor responsible for the defect has been definitely established. Most authors agree that a developmental defect of the bone or dura, or both, precedes the appearance of the meningocele.⁶ Which of these defects is more important is likewise undetermined.



A.

B.



C.

Fig. 1.—Radiographs taken in the posteroanterior (A), left lateral (B), and left anterior oblique (C) positions show a mass in the apex of the left lung field.

RESULTS OF SUPERVOLTAGE ROENTGENOTHERAPY OF ESOPHAGEAL CARCINOMA

FRANZ BUSCHKE, M.D., AND S. T. CANTRIL, M.D.
SEATTLE, WASH.

WE HAVE repeatedly discussed the rationale of supervoltage roentgenotherapy for epidermoid carcinoma of the esophagus, its indications, contraindications, and technical details. More recently we have presented a comparison of the optimal surgical and radiologic results obtained to date.⁵ The following article is a summary of our own results in patients treated between January, 1940, and July, 1952. For technical details of treatment we refer to our previous publications.^{1, 3, 4}

A total of fifty-eight patients was seen (Table I). Nineteen of these were not treated, in most instances because either the lesion was too advanced to expect even temporary sustained palliation, or the general condition was too poor to support such a major procedure. Twelve patients received what we would consider grossly inadequate therapy, usually because treatment had to be discontinued on account of the rapidly declining general condition.

Twenty-seven patients received what we would consider adequate treatment. By this we mean that a minimal dose of 5,000 r., calculated at the level of the esophagus, in about forty to forty-five days, or its equivalent with greater fractionation, was delivered. Of these patients, five are in clinically satisfactory condition today.

Considering only patients who have been treated more than five years ago, twenty-nine were seen of whom five received incomplete, and fourteen complete treatment, as previously defined. Three patients are well without radiographic or clinical evidence of disease. They have been living a perfectly normal life in every respect for periods of twelve, ten, and eight years, respectively. One of these had disease localized in the cervical segment, one in the upper, and one in the lower thoracic segment of the esophagus. Thus three patients have been well for more than five years out of a total of twenty-nine patients examined, or out of nineteen patients who were admitted for treatment (corresponding to surgical exploration), or out of fourteen who were completely treated (corresponding to patients in whom surgical resection would have been completed). In addition, two patients have been clinically well, possibly with controlled disease for two and three years, respectively. One had a carcinoma in the upper thoracic and one in the mid-thoracic portion. These two patients do not have restoration of a normal esophagus insofar as both have a moderate degree of obstruction. This, however, has remained entirely stationary in one patient for fifteen months, in the other for eighteen months. Since the stenoses in these patients have not

From the Tumor Institute of the Swedish Hospital.
Received for publication, Jan. 26, 1953.

Treatment by excision seems to be fairly safe with modern surgical techniques. Resection was not attempted in two cases because of lack of symptoms and the relatively safe location of the tumor.⁵ The choice of treatment must of necessity be individualized.

SUMMARY

1. A case of intrathoracic meningocele is reported; we believe it to be the fifteenth proved case in the literature.

2. Roentgen findings common to most of the cases of this type are kyphoscoliosis, a mediastinal tumor, evidence of erosion of either the vertebral bodies or adjacent ribs, and vertebral deformities or anomalies. An important associated clinical finding is the presence of neurofibromatosis which was present in ten of the fifteen proved cases comprising this series. Neurofibromas associated with a tumor located paraspinally in the chest should initiate a search for meningocele by myelography.

ADDENDUM

Since this article was written, another case of intrathoracic meningocele proved by aspiration has been recorded. Ottani, Gerardo: Intrathoracic Meningocele, *Ann. di radiol. diag.* 23: 416-419, 1951. (Abstracted in *Radiology* 59: 132, 1952.)

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months after completion of treatment without clinical or radiographic signs of active disease in esophagus, mediastinum, or elsewhere was attributed to general weakness and age. Obviously, surgery would not have had any better chance of success in any of these patients. In only one instance can it be argued in retrospect that surgery might have been more successful. This patient died twenty-five months after very massive therapy from what we believed was probably massive mediastinal and pulmonary fibrosis rather than active disease. This patient was treated in 1941, a time when resection of the mid-esophageal portion still carried a prohibitive surgical risk. Even in this instance, it remains doubtful what surgery could have accomplished in the presence of a disease which had caused symptoms necessitating regular dilatation for more than one year prior to referral to us.

Thus it appears that in these eight patients, roentgenotherapy has accomplished satisfactory palliation preventing starvation for periods of five to twenty-five months during which time these patients lived practically normal lives, in one-half of the instances for periods exceeding one year.

The analysis of the remaining fourteen failures shows that in these instances the primary disease remained uncontrolled and progressed. Perforation into the tracheobronchial tree, mediastinum, or aorta one to seven months following completion of therapy was the cause of death in six patients. In two cases death was due to generalization of the disease, and in one instance to ascending urinary infection secondary to a cord bladder caused by vertebral involvement by metastatic disease one month after completion of therapy.

In these fourteen cases in which the primary disease progressed following radiation therapy, the question of whether surgery could have accomplished more becomes even more urgent. Six of these patients were referred to us by three of the leading thoracic surgeons in the community because they were considered inoperable: four because of demonstrable extraesophageal extension (radiographically demonstrable penetration or mediastinal nodes); one with an anaplastic carcinoma of 10 cm. length with the history of symptoms for more than nine months; one because of the general condition and age. Three additional patients were considered inoperable because of general condition and age, one of these with fibrillation prior to therapy, and one with Parkinson's disease. Two patients had extensive cervical and mediastinal lymph node involvement prior to therapy. One patient had a carcinoma extending from the inferior level of thyroid cartilage to the fourth dorsal interspace. The patient previously mentioned, who developed metastatic involvement of one vertebra with cord bladder one month after treatment, would obviously not have been benefited by surgery. There remains one patient, aged 72 years, with a lesion at the level of the sixth thoracic vertebra in whom a very aggressive thoracic surgeon may perhaps have considered surgery (C. J., 44-). The last patient to be accounted for (J. P., 47-477) was 58 years old and in good general condition at the time of admission; he was offered the choice of surgery with its inherent risk and an attempt with radiation therapy. Two months following the completion of treatment, this lesion appeared uncontrolled although it could not be determined whether the findings were due

TABLE I. EPIDERMOID CARCINOMA OF ESOPHAGUS

	NO. SEEN	NOT TREATED	INCOMPLETELY TREATED	COMPLETELY TREATED	WELL JULY 1, 1952
January, 1940—July, 1952	58	19	12	27*	5†
January, 1940—July, 1947	29	10	5	14	3‡

*Histologically verified by biopsy or autopsy.

†Two patients well two and three years, respectively.

‡One lesion in cervical, upper thoracic, and lower thoracic segment, respectively.

changed over this long period of time and have remained radiographically smooth, we believe that they are more likely caused by fibrotic scarring than by active disease. One of these patients needs occasional dilatation. Both feed themselves satisfactorily by semisolids.

None of the patients with lesions in the mid-thoracic portion of the esophagus has remained well. The question then arises whether surgery would have offered any of these patients a better chance of control.

An analysis of the twenty-two failures shows that in eight instances roentgenotherapy accomplished re-establishment of the normal esophageal passage to the point that these patients could eat normally, or almost normally, up to the time, or very shortly prior to the time, of death. Death was not due to recurrent obstruction or demonstrable recurrent disease in the site of primary origin. The analysis of the cause of death in these eight patients (Table II) shows that in five instances failure of permanent control was due to the presence and progression of paraesophageal and mediastinal nodes; in one patient death was due to liver metastases. In one patient, death thirteen

TABLE II. EPIDERMOID CARCINOMA OF ESOPHAGUS. CAUSE OF DEATH IN PATIENTS IN WHOM FOLLOWING IRRADIATION NORMAL OR ALMOST NORMAL ESOPHAGEAL PASSAGE WAS MAINTAINED UNTIL DEATH OR UNTIL VERY SHORTLY PRIOR TO DEATH

INITIALS	NO.	AGE	LOCATION	DURATION SYMPTOMS PRIOR TREATMENT (MO.)	DOSE* R./DAYS	DURATION END OF TREATMENT TO DEATH (MO.)	CAUSE OF DEATH
J. R.	41-	62	M	12	(16200/81)	25	Fibrosis
G. G.	44-	58	L	14	(14000/61)	15	Paraesoph. node 1 yr. p. rad.
B. S.	46-740	50	C	4	6500/52	6	Paraesoph. node
I. G.	47-456	61	L	16	5000/44	19	Liver metastasis
D. B.	48-341	76	C & U	7	(7100/30)	9	Extrinsic obstruct. node lower esoph. 9 mo. p. rad.
M. P.	50-22	55	C	2	6000/36	6	Mediast. nodes
J. O.	50-620	76	M	3 wk.	6000/39	13	General weak- ness; age
O. W.	51-975	60	M	2	7000/45	5	Perfor. of mediast. node; acute massive hemorrh.

C—Cervical segment.

U—Upper thoracic segment.

M—Mid-thoracic segment.

L—Lower thoracic segment.

*Dose in parentheses is measured at skin in patients in whom chest measurements are not available for computation of tumor dose. Figures of dose without parentheses represent tumor dose as calculated at level of esophagus.

Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The 34th annual meeting of the American Association for Thoracic Surgery will be held May 3, 4, and 5, 1954, in Montreal, Que., Canada. Headquarters will be at the Sheraton-Mount Royal Hotel.

Requests for Hotel Reservations

These should be mailed *directly* to the Reservation Manager, Sheraton-Mount Royal Hotel, Montreal, Que., Canada. Please mention this Association, type of accommodation desired, date, and approximate hour of arrival. If accommodations are desired elsewhere, please communicate directly with hotel of your choice.

Thoracic Surgical Forum

After due consideration, the Council has decided to try an experiment by assigning one morning session to a "Thoracic Surgical Forum" for the presentation of short papers on current thoracic research, anatomy, modified surgical techniques, etc. Papers at this session will be limited sharply to ten minutes (including the showing of lantern slides or other illustrative material) with three minutes as the maximum discussion of each paper.

These papers will be published together in one issue of THE JOURNAL OF THORACIC SURGERY. Maximum length: 3,000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts for Papers

Abstracts for the presentation of papers at the 1954 meeting, including papers before the Forum, must be received on or before January 1, 1954, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Forum" or "For Regular Program."

Five, *repeat five*, copies of each abstract should be sent to the Secretary of the Association, Dr. Paul C. Samson, 2938 McClure St., Oakland 9, Calif. They should not be sent to the Editor.

The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Jan. 1, 1954, to be considered for action in Montreal. Applications received beyond this deadline will be deferred for consideration until 1955.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the sponsoring statement on the application form, the sponsors must submit a separate letter concerning the applicant direct to Dr. Lyman H. Brewer, III, Chairman of the Membership Committee, 2010 Wilshire Blvd., Los Angeles, Calif. Completed application forms should likewise be sent to Dr. Brewer. These regulations are at the direction of the Council and were made effective in 1952 at Dallas.

to active disease or to massive radiation reaction and necrosis. At that time, therefore, it was felt that the likelihood of uncontrolled disease was sufficiently great to justify the risk of surgery. Resection of a 9 cm. mid-esophageal segment with primary esophagogastrostomy was done. In spite of the heavy preceding irradiation (4,800 r. in forty days calculated at the esophageal level) healing progressed without complications and the patient was discharged ten days following surgery. No carcinoma was found in serial sections of the removed specimen. Six days after discharge from the hospital, the patient was killed in an automobile accident. At autopsy carcinoma was found infiltrating the esophageal wall about 5 mm. above the site of the anastomosis and a carcinomatous nodule 1 cm. in diameter at the level of the anastomosis.

Thus it would seem that none of the patients not saved by radiation therapy would have had a better chance if surgery had been elected.

SUMMARY

1. Between January, 1940, and July, 1952, fifty-eight patients with carcinoma of the esophagus were seen. Five out of twenty-seven adequately treated, or of thirty-nine patients in whom treatment was started, are clinically well today.

2. Of twenty-nine patients seen more than five years ago, nineteen were admitted for treatment and fourteen of these received adequate therapy. Three of these patients have been clinically and radiographically well, without any sign of active disease with normal esophageal function, for periods of twelve, ten, and eight years, respectively.

3. Of twenty-two patients adequately treated but uncontrolled, normal or almost normal esophageal function until death, or until shortly prior to death, was accomplished in eight instances for periods between five and twenty-five months. In six of these patients death was due to extraesophageal progression of the disease, in one to general weakness caused by age, and in one probably to massive mediastinal and pulmonary fibrosis.

4. Analysis of the twenty-two adequately treated but uncontrolled cases suggests that in only one of them surgery may possibly have offered a better chance.

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Original Communications

HYDATID DISEASE AS IT AFFECTS THE THORACIC SURGEON

M. P. SUSMAN, F.R.C.S. (ENG.) (BY INVITATION)

SYDNEY, AUSTRALIA

HYDATID disease is due to the development in man of the cystic (larval) stage of the tapeworm *taenia echinococcus*. The adult stage is passed in the intestine of the dog or of a member of the dog tribe (dingo, jackal, wolf), and the cystic stage generally occurs in one of the herbivorous animals (sheep, ox, pig) or in man. An infected dog passes thousands of ova in the feces and these are swallowed by the intermediate host in contaminated water or food and are carried in the blood stream to various organs where they develop into hydatid cysts. Man can be infected in the same way, but more frequently he contaminates his fingers by handling a dog and then takes his food without washing his hands. Dogs become repeatedly infected by being fed with the cyst-bearing offal of the intermediate host. Each mature cyst generally contains thousands of scolices (tape worm heads) which grow into adult worms in the dog's gut, and so the cycle repeats itself indefinitely. It is obvious that the disease can be prevented by two simple measures: first, dogs should not be allowed to eat infected offal, and second, human beings should always wash their hands after handling dogs. But so far all efforts by education and exhortation have failed to eliminate hydatid disease and this makes one wonder what hope there is of preventing the more widespread and complex infection with the tubercle bacillus.

The incidence of hydatid disease in man runs parallel to the incidence of infestation of the dog and sheep; the other possible definitive and intermediate hosts play little or no part in the spread of the disease to man.

Unfortunately, this parasite, like some of its biologic betters, may lead a double life. The scolex which, as explained above, normally depends for its continued existence on reaching the final host, has the power in certain circumstances of becoming a cyst itself in the intermediate host. There may be a natural tendency for this to occur at some time in a normal cyst, but it usually happens only if the mother cyst is injured; scolices are set free and they grow into daughter cysts within the confines of the mother cyst or in any tissue or

From Sydney Hospital and Royal North Shore Hospital.
Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 29, 1953.

Greetings to Thoraxchirurgie

The JOURNAL of THORACIC SURGERY takes pleasure in welcoming to the same field *Thoraxchirurgie* of which the first number has appeared under date of April, 1953. The new journal will be devoted to clinical and operative surgery, pathologic physiology, experimental pathology of the thoracic viscera, and to anesthesia.

It will be under the editorial direction of Professor K. Vosssehulte of Giessen, assisted by A. Lezius of Hamburg and R. Nissen of Basel. The all-European editorial board contains the names of several thoracic surgeons well known to Americans, among whom are Brock, Crafoord, Denk, Dogliotti, Felix, and Santy. *Thoraxchirurgie* will be published by the experienced firm of Georg Thieme of Stuttgart, the publishers of *Deutsche medizinische Wochenschrift*, and an issue will appear every two or three months.

The first number, with a foreword by Nissen, makes a splendid impression. It is gratifying that a new journal has appeared devoted to thoracic surgery which will be published in the language used by Sauerbruch for his pioneer contributions to this field.

The Editor

5. The parasite may die at any time for no apparent reason, or as the result of rupture or pyogenic infection. It may become a caseous mass very like a tuberculous focus.

6. The rate of growth of these cysts is not known. It has often been said that most patients become infected in childhood although the disease may not be diagnosed until adult life. But radiology has shown that a hydatid cyst may become apparent in a matter of months; if infection did actually occur in childhood in these persons, then for many years the cysts were too small to cast an appreciable shadow and then they suddenly took on rapid growth. Furthermore daughter cysts may appear in radiograms taken during the first year after rupture of a mother cyst. It is probable that primary and secondary cysts have different rates of growth and the rate of growth varies from animal to animal, as well as in the same animal.

7. It is not known when and where the ova hatch out. But we do know that the embryos enter the portal circulation and that explains why most hydatid cysts are found in the liver. One or more embryos may pass through the liver and reach the lungs which are the second most frequent site of cysts. Again some embryos pass through the lungs and enter the general circulation. Thus cysts may develop in any part of the body, but the total number in other organs and tissues is much less than the number in the lungs and liver. Cysts in different parts frequently coexist.

8. Hydatid cysts grow by quiet pressure necrosis of surrounding structures and any tissue may become seriously eroded, including bones and blood vessels.

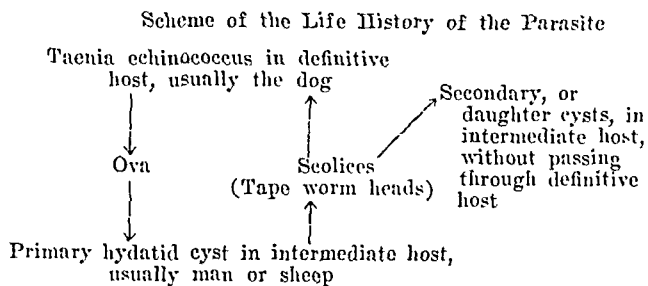
DIAGNOSIS

Simple cysts are usually latent and may only be discovered by the finding of a swelling, or by routine radiography of the lungs. Sometimes there may be symptoms from pressure, but as a rule symptoms are due to the anaphylactic, mechanical, and infective sequels of rupture of the cyst. After its rupture a hydatid may mimic many other conditions; for example, a ruptured cyst of the lung may be mistaken for neoplasm, tuberculosis, and other infections; and a ruptured cyst of the liver is often mistaken for cholelithiasis or one of the various types of jaundice. If the possibility of hydatid disease is remembered the diagnosis can often be made by certain tests and examinations and by correctly interpreting anaphylactic phenomena.

ANAPHYLAXIS

Anaphylaxis is responsible for most of the alarming symptoms that follow rupture of a hydatid cyst; it is due to the absorption of hydatid antigen in a person who has been already sensitized by the small dose that he receives during the development of the cyst. The patient may be so sensitive that even the small amount of antigen used for the Casoni test may produce alarming symptoms. These symptoms are very variable and only rarely do all possible ones appear in the one patient: *Cutaneous* (rashes, itchiness, and sweating), *Alimentary* (vomiting, diarrhea, and colic), *Respiratory* (asthmatic attack, cyanosis, edema of the lungs, and glottis), *Cardiovascular* (pallor, tachycardia, and collapse), and *Nervous* (pyrexia, fits, delirium, and coma).

organ that they reach by direct implantation or by the blood stream. Cysts which develop from ova are called primary cysts, and cysts that develop from scolices are called secondary cysts. The essential difference between them is that primary cysts develop from eggs passed by the final host, and secondary cysts develop in the intermediate host direct from scolices that pass no part of their life in the final host.



Daughter cysts are exact replicas of their mother; they all consist of two layers, the ectocyst or laminated membrane and the endocyst or germinal layer. The ectocyst is made of successive layers of elastic hyalin derived from the endocyst. From the inner face of the endocyst which has a fine, nucleated structure, grow the brood capsules with their scolices; this layer also secretes the watery fluid which is characteristic of the hydatid cyst. The parasite provokes a local reaction around itself, and the host responds by laying down a fibrous barrier called the pericyst or adventitia, which tends to become thicker and tougher with age. It has no organic connection with the cyst itself.

There is still some confusion about the use of these terms and it is essential to note that the adventitia or pericyst is part of the host and that the ectocyst, endocyst, the enclosed fluid, and live elements make up the parasite. A cyst is described as simple when it still retains its original virginal state, and complicated when it has suffered injury, rupture, and infection.

Certain biologic features influence the incidence of the disease and its distribution in different organs:

1. The ova are hardy and resistant; the scolices are delicate and labile. In practical terms this means that the intermediate host may become infected long after the ova have been excreted by the dog; but the dog will become infected only if he eats the scolex-bearing cysts while they are still fresh and unruptured.

2. Only a small percentage of human beings, dogs, and sheep are susceptible to infection.

3. Many ova that reach the intermediate host fail to develop into cysts and many cysts abort at an early stage.

4. The distribution of cysts in the body varies from country to country and from species to species. In Australia and New Zealand about 23 per cent of the cysts in human beings occur in the lungs; in Iceland the percentage given by Icelandic investigators is only 1.5 per cent. Cattle have proportionately more pulmonary cysts than sheep, and pigs have fewer. Cysts are rare in the horse, and a very high percentage of them occur in the liver.

5. The parasite may die at any time for no apparent reason, or as the result of rupture or pyrogenic infection. It may become a caseous mass very like a tuberculous focus.

6. The rate of growth of these cysts is not known. It has often been said that most patients become infected in childhood although the disease may not be diagnosed until adult life. But radiology has shown that a hydatid cyst may become apparent in a matter of months; if infection did actually occur in childhood in these persons, then for many years the cysts were too small to cast an appreciable shadow and then they suddenly took on rapid growth. Furthermore daughter cysts may appear in radiograms taken during the first year after rupture of a mother cyst. It is probable that primary and secondary cysts have different rates of growth and the rate of growth varies from animal to animal, as well as in the same animal.

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It is important to remember that even in severe cases there may be no telltale rash. Recovery is the rule but there may be a repetition following fresh rupture or operation. The anaphylactic symptoms may be so slight that they are overlooked or forgotten and the patient presents with the mechanical or infective sequels to the rupture, or perhaps only still later with evidence of daughter cyst formation.

SPECIAL EXAMINATIONS AND TESTS

1. If a cyst ruptures into the bronchial tree hydatid elements may be found in the sputum. If it ruptures into the biliary tract, hydatid material may be recovered from the feces or from duodenal washings, and if it ruptures into the urinary tract, the material may be found in the urine. A suspected cyst should never be deliberately punctured because of the risk of spread and of anaphylaxis, but if a puncture is made in error, advantage should be taken of it and the fluid should be examined. If a pulmonary cyst has ruptured into the pleural cavity, hydatid elements may be recovered from the aspirated fluid.

2. Differential white cell count of the blood. Eosinophilia is found in about half the patients before operation. It has no direct diagnostic value, but it is suggestive in a suspected case when other common causes of eosinophilia are excluded.

3. Casoni intradermal test.* This is a test for anaphylaxis, the test being positive in a patient who has been sensitized to the hydatid antigen. The reagent is pooled hydatid fluid from uncomplicated cysts of sheep. Immediate and delayed reactions are looked for:

a. An immediate reaction is of value only before the first operation, and it occurs in about 75 per cent of patients with uncomplicated cysts and 92 per cent with complicated cysts.

b. Failure to react practically excludes a ruptured or suppurating cyst and means an absence of any cyst in 95 per cent.

c. A positive reaction may persist for years after operation without fresh infestation; a negative test after operation usually signifies a cure.

d. An immediate positive reaction does not certainly mean hydatid disease, as it may occur in certain skin diseases, allergic states, and other helminthic infections.

e. The delayed reaction occurs in only one-quarter to one-half of patients before operation, but it is practically diagnostic. It is of no value in the diagnosis of recurrent or residual cysts.

4. Complement fixation test. This is a specific test for antibodies and is positive in 50 to 60 per cent of patients before their first operation and in about the same percentage of patients with recurrent or residual cysts a year or more after operation. The pathologic state of the cyst influences the result of this test:

a. With uncomplicated cysts it is more often absent than present.

b. It is almost always positive within a month of rupture or infection, but may become negative within two months of these complications.

*The figures given here are based on Dew and other authors. In my experience there have been more negative and fewer positive results.

c. With early degeneration of a cyst it may be positive, but with complete degeneration it is negative.

d. A high figure in a patient who has had no operation usually means that the cyst is complicated.

e. A high figure nine or more months after operation is almost diagnostic of more cysts, and a negative result three months after operation almost certainly spells cure.

f. A negative result excludes recent rupture or suppuration (except when the cyst contains no antigen).

5. Precipitin test. The results of this test follow closely those of the complement fixation test; it is not favored nowadays because of the difficulty of obtaining satisfactory antigen.



Fig. 1.

Fig. 2.

Fig. 1.—There is one large hydatid cyst in the right lung and two smaller cysts in the left lung.

Fig. 2.—The cyst has ruptured and the parasite has been expectorated, leaving an ill-defined opacity. This later cleared completely and it has remained clear in the ensuing seven years. (This is a case of probable cure by expectoration.)

RADIOLOGIC APPEARANCES

Pulmonary Cysts.—A well-defined, rounded, or oblong opacity in the lung field is characteristic of the simple uncomplicated hydatid cyst (Fig. 1). A similar shadow may be given by a peripheral cancer, a nerve tumor, a mediastinal dermoid, developmental cyst, a chronic lung abscess, diaphragmatic hernia, metastatic malignant deposits, or an aneurysm. When a hydatid cyst ruptures into a bronchus the definite regular outline is lost and there may be a blurred shadow that can be mistaken for a tuberculous focus, a lung abscess, or carcinoma (Fig. 2). Often a more distinctive picture is given of a cavity with a fluid level which is broken by the top of the collapsed cyst floating in it (Fig. 3). Occasionally all the fluid and some or all of the parasitic membranes will be expectorated and leave the cyst cavity distended with so much air that it

resembles a pneumothorax or a developmental lung cyst (Fig. 4). Occasionally calcification may be detected. If rupture occurs into the pleural cavity the radiologic appearances may resemble any kind of pleural effusion. Sometimes the cyst is still distinguishable through or above it. An effusion is rare apart from rupture (Fig. 5). Bronchograms are rarely helpful and tomography has not yet been evaluated.

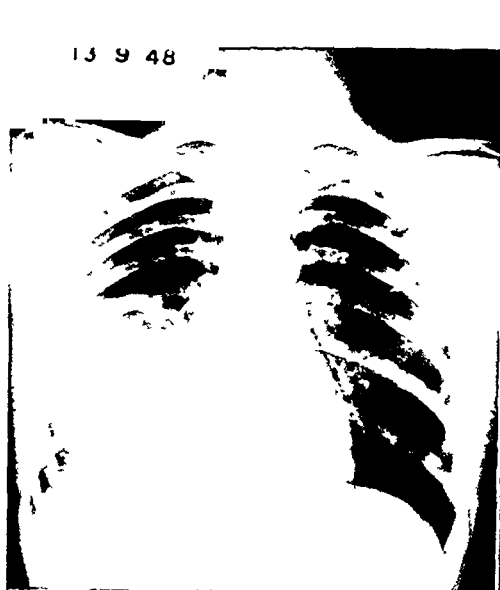


Fig. 3.



Fig. 4

Fig. 3.—The cyst has ruptured and there remains a pocket of air above a collection of fluid and collapsed membranes

Fig. 4.—Rupture of the cyst has left a large air-distended space

Hepatic Cysts.—Calcification is more common in liver cysts than in lung cysts; it is well shown in radiograms and is practically diagnostic. In the absence of calcification there may be the indirect evidence of a raised, distorted, or partly paralyzed diaphragm (Fig. 6). If the cyst becomes infected with gas-forming organisms or if it ruptures into a bronchus, the x-ray appearances are those of a cavity with air and a fluid level. At other times rupture of an hepatic cyst into the lung may produce all kinds of bizarre pictures, some of which have been compared to a volcano in eruption (Fig. 7). A hepatic cyst, without directly involving the thorax, causes a pleural effusion more frequently than does a pulmonary cyst. A diagnostic pneumoperitoneum may help to distinguish between a hepatic cyst and a pulmonary basal cyst.

Cysts of the Heart and Pericardium.—The radiologic appearances are not characteristic. There will be an increase in the size of the usual heart shadow if the cyst is sufficiently large. If the cyst is at the periphery there will be a round shadow continuous with the heart shadow and under the screen transmitted pulsation may be evident (Fig. 8).

COMPLICATIONS OF PULMONARY CYSTS

A. *Rupture Into a Bronchus.*—Most cysts of the lung if not operated on will break into a bronchus by pressure necrosis. This may result in cure by expectoration but often it ends in morbidity or disaster. The immediate sequels of

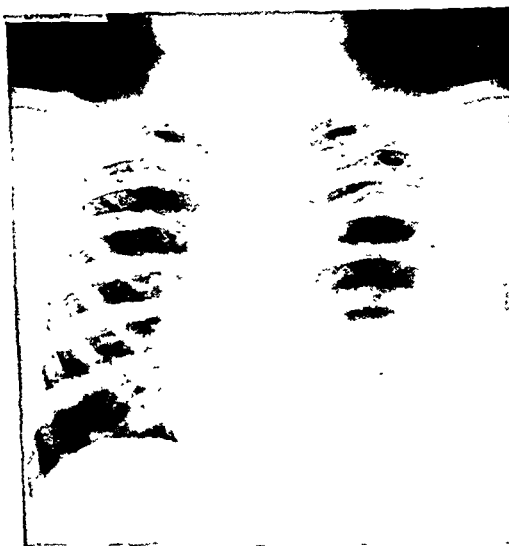


Fig. 5.

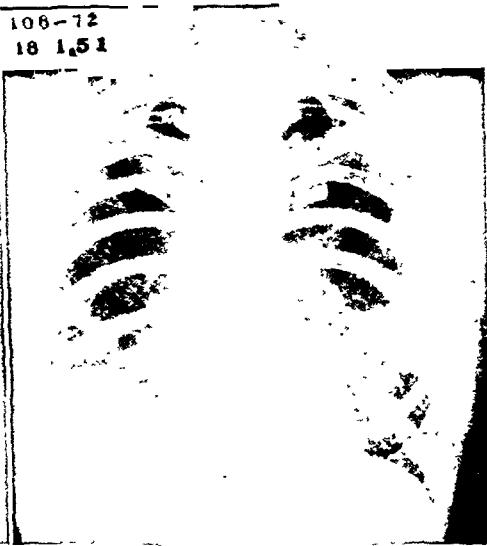


Fig. 6.

Fig. 5.—The cyst has ruptured into the pleural cavity. There is a pyopneumothorax and the collapsed cyst can be seen in the lowest part of the chest.

Fig. 6.—This is a hepatic cyst pushing the diaphragm upward. It could be mistaken for a pulmonary cyst; pneumoperitoneum may help to distinguish one from the other.

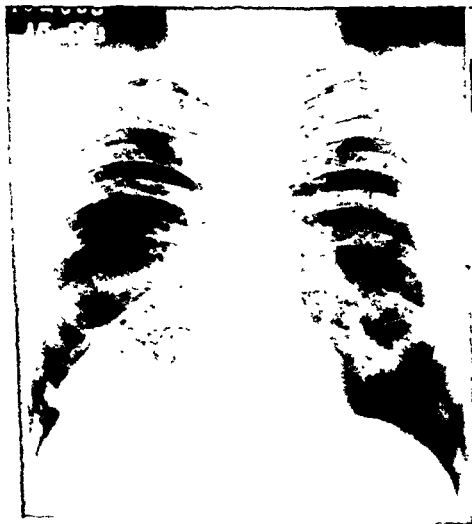


Fig. 7.



Fig. 8.

Fig. 7.—This is an hepatic cyst eroding the diaphragm.

Fig. 8.—The right cardiophrenic angle is occupied by a large cyst containing daughter cysts. At operation it was found to involve the pericardium and mediastinum. The other opacities are due to cysts in the chest wall probably growing from scolices implanted at a previous operation for an hepatic cyst.

rupture may be: a. Asphyxia from impaction of membrane in the trachea or larynx, or from flooding of both bronchi with the fluid from a large cyst, b. acute anaphylactic shock, and c. hemorrhage, which is rarely severe.

Later results are: a. Retention of all or some of the membrane, fluid only being coughed up. This fluid may later have an orange-yellow color, which is a diagnostic pointer (Fig. 3). b. Infection of the cyst space, often associated with recurrent hemoptyses. c. Development of daughter cysts in one or both lungs from scolices that were dispersed through the bronchi at the time of rupture (Figs. 9 and 10). d. Development of daughter cysts in the original cyst space. e. Distension of the cyst space into an air cyst (Fig. 4).

Sometimes the rupture is little more than a small leak; this may close and the life of the parasite continue unchanged.



Fig. 9.

Fig. 10.

Fig. 9.—Here is a ruptured cyst of the left upper lobe. The collapsed membranes are at the bottom and a large air space is above them. All the fluid was expelled.

Fig. 10.—This radiogram was taken one and one-half years after operation on the cyst shown in Fig. 9. Three simple cysts are well seen (four were found at operation). They are almost certainly daughter cysts due to the intrabronchial spread of scolices. She has since coughed up another.

B. Rupture Into the Pleural Cavity.—The sequels of this event are: a. Pneumothorax, b. Empyema or pyothorax, and c. Development of daughter cysts from the spilt scolices.

Immediate operation may prevent the last two complications, but often the patient does not come to surgery until one or both are already present. If infection occurs early all the scolices may die and so there will be no daughter cysts. If infection is delayed, daughter cysts may have already developed and they continue to live, in spite of the sepsis. The diagnosis of intrapleural rupture is often missed at first and may not be made until examination of

aspirated fluid reveals hooklets and many eosinophils. Sometimes the cyst fails to rupture when the pericyst gives way and the intact parasite continues to thrive in the pleural cavity, acquiring a new pericyst in time.

C. Rupture Into the Vascular System.—Rupture of a pulmonary cyst into the pericardium, heart or pulmonary vessel is rare. The results of intravascular rupture of a hydatid cyst are described later.

OPERATIVE TREATMENT OF PULMONARY HYDATID CYSTS

Every hydatid cyst in the lung should be removed unless there is some good reason for advising against operation. The present operative mortality lies between 1 and 2 per cent, and the risk is less with small and simple cysts than with large or complicated cysts. It is true that a natural cure may follow rupture into a bronchus and expectoration of the cyst, but the dangers attending this rupture are, as already stated, too great to justify waiting. There are also the dangers of rupture into the pleural cavity and vascular system. For these reasons operation should be advised as soon as the diagnosis is made.

The objects of operation are:

(1) Complete removal of the cyst, (2) avoidance of soiling and infection, (3) obliteration of the space which the cyst occupied and closure of bronchial fistulas, and (4) prompt re-expansion of the lung.

The types of operation are: 1. *Conservative*. Removal of the parasite alone, or with the pericyst (adventitia). 2. *Radical*. Resection of the lung or part of the lung.

Conservative surgery suffices for almost all simple cysts and for most complicated cysts. Radical surgery may be necessary for a simple cyst if serious hemorrhage occurs during a conservative operation, or if it has replaced most of the lobe (giant cyst)—a doubtful indication.

Radical surgery may be required for a complicated cyst for recurrent hemoptysis, for gross sepsis in and around the cyst, and for troublesome bronchiectasis.

In practice, I have personally never done a radical operation for a simple cyst, and I have done it only three times for a complicated cyst, each time because of recurrent hemorrhage. Radical surgery is justified if the diagnosis is uncertain and the surgeon knows only that there is an undetermined radiologic opacity and a "lump" in the lung. Radical surgery by resection will not be discussed in detail as it is the standard dissection operation, but it may be unusually tedious because of dense adhesions. Pneumonectomy will be rarely required, and at the most only lobectomy should be called for. Conservative operations merit further discussion.

CONSERVATIVE OPERATIONS FOR HYDATID CYSTS OF LUNG

Simple Cysts.—

1. Removal of the parasite alone. This may be achieved in two ways:

a. Removal After Aspiration. The cyst is exposed through a comparatively small incision if it is adherent to the chest wall and has been correctly localized, or through a wide thoracotomy if it is not adherent, or not easily accessible. The advantages of operating through an adherent zone are that there is no risk of pleural soiling and there is no pneumothorax to be dealt with. But a free thoracotomy is so safe nowadays that it should be used without hesitation if it is necessary or helpful. The cyst is carefully isolated from surrounding structures and a medium bore needle connected to a sucker is pushed into it and as much fluid as possible aspirated. A second sucker with a small flat nozzle is immediately placed alongside the needle puncture to pick up any fluid that may leak through it. With these precautions there is little risk of any soiling by hydatid material. When no more fluid can be aspirated the needle is withdrawn, with precautions taken against anything dripping from it.

The lax pericyst is opened between two holding forceps and the membranes are removed. The inside of the pericyst is inspected with a light: generally it will be found rough but clean and one or more small bronchial fistulas will be seen. These fistulas are closed and the cavity of the pericyst obliterated by placing a continuous suture of catgut in the deepest part and going back and forth, each time at a higher level, until the walls of the space are closely approximated. If the last suture line is adjacent to the chest wall it is fixed to it by the same or a fresh suture; but if the suture line does not face the periphery, the lung is allowed to drop back. The object of attaching the pericyst to the chest wall is that it will be readily accessible if hemorrhage or infection should occur in it necessitating drainage. If there is a free pleural space a drainage tube, for connection to a water seal, is inserted through a stab wound. This is to promote rapid expansion of the lung, to anticipate possible soiling or infection and to avoid a tension pneumothorax should any bronchial fistula not have been securely closed. The tube can usually be removed within several days and recovery is generally prompt and uninterrupted.

I emphatically disagree with the dogmatic statement of Barrett and Thomas² that this type of operation "is bad and should be given up." It is safe and simple; it is suitable for most cysts; and with care, soiling can be avoided.

b. Removal of the Parasite Intact. In this method the hydatid fluid is not aspirated. The cyst is carefully insulated and an incision is made in the pericyst down to, but not into, the parasitic membranes. By careful dissection and by having the anesthetist raise the intratracheal pressure, it is possible to remove the cyst intact. If it succeeds it is a most satisfactory operation as no soiling can occur. The rest of the operation is the same as in the one already described. There is an appreciable risk of accidental rupture of the cyst during this attempt to remove it intact and if rupture does occur the risk of soiling with hydatid elements is much greater than in the operation of first aspirating the fluid. I and other surgeons have done the operation successfully without rupturing the cyst since Barrett¹ suggested it, but most of us, like Barrett, have had the cyst rupture on us, and I doubt whether the successful cases justify the risks of failure.

In discussing these two operations Barrett and Thomas² emphasize the risk of contamination by aspirating the cyst before removing the membranes, but they also say that if the cyst ruptures during the attempt to remove it intact, "the patients were no worse off than if they had been treated by other ways." It is difficult to reconcile these views, because inadvertent opening of the cyst spills much more fluid than ever escapes with deliberate aspiration. If soiling occurs, it is too early to say that daughter cysts will not develop until some years have passed.

Complicated Cysts.—The second of these two operations is not applicable to a complicated cyst, because, having already ruptured, it is no longer intact. The first operation can be applied if allowance is made for the fact that aspiration is ineffective now that the cyst has ruptured; at the most only a trace of turbid fluid will be discovered. With the usual precautions against soiling the pericyst is opened and the collapsed membranes with any residual fluid or daughter cysts are removed. The cyst space, after gentle swabbing, will usually be clean enough to obliterate and close, but if it appears to be too dirty a drainage tube is left in it for a day or two. The pericyst is fixed to the chest wall if possible and the pleural cavity is drained in the usual way.

2. Removal of the cyst with its pericyst.

This operation is suitable for both simple and complicated cysts, and it offers the best chance of avoiding soiling. I had my first experience with it three years ago when I was operating on a girl with five cysts in the left lung due to intra-bronchial spread after rupture of a cyst of the right lung.³

In this report no operative details were given but they are of interest for the present discussion. None of the cysts was more than one inch in diameter and all were near the surface of the lung. One ruptured during the attempt to remove it intact after incising the pericyst. Each of the remaining four was removed intact with its pericyst and this proved to be a very satisfactory procedure which I have used since for similar small cysts. I did not employ it for larger cysts until stimulated by Barrett and Thomas,² who state that the larger the cyst the easier it is to enucleate with its adventitia. This may be so, but to me it is more of a major procedure when the cyst is large and buried in the lung substance than when it is small and superficial. This is a better operation than removal of the parasite alone because: a. The risk of soiling is less. b. With proper selection it can be used for both simple and complicated cysts. c. It may replace lobectomy in suitable cases.

SUMMARY OF TREATMENT OF PULMONARY CYSTS

1. The best operation for most simple cysts consists of aspiration of the fluid, removal of the parasitic membranes, obliteration of the cyst space and drainage of the pleural cavity. With care there should be no soiling.

2. Most complicated cysts do well with a similar operation with suitable modifications.

3. If the surgeon, from choice or necessity, decides to remove the cyst intact, he can do it most surely by enucleating it with the pericyst rather than by removing the parasite alone.

OPERATIVE TREATMENT FOR RUPTURE OF CYST INTO THE PLEURAL CAVITY

Conservative surgery will usually suffice for this serious complication and the earlier it is done the better. The objects of the operation are: (1) to remove all parasitic material from the lung and pleural cavity, (2) to close any obvious bronchial fistulas, and (3) to drain the pleural cavity and to have the lung re-expanded as soon as possible.

Even when sepsis and/or daughter cysts are present these measures will generally succeed. I do not agree with the suggestion of Barrett and Thomas that rupture of a pulmonary cyst with the formation of daughter cysts in the pleura should be treated by pleuropneumectomy.²

CYSTS OF THE DIAPHRAGM

Between 5 and 6 per cent of hydatid cysts occur in muscles. As these have been infected through the blood stream it is not surprising that most of the patients have or have had cysts in the liver or lung. They start as ordinary simple cysts but most of them have daughter cysts by the time they are discovered.

The diaphragm is a rare site and I have reported the only one that has come to my notice.⁴ It occurred in a patient, aged 63, who complained of a dry cough and pain. He said that he had coughed up blood several times in the past and this may have been due to cysts in the lung. Radiograms showed an irregularly rounded shadow in the right cardiophrenic angle. At operation a hard mass was removed intact with a fringe of the diaphragm and pericardium. It was not connected to the heart, lung, or liver, and no cysts were found in these organs. The specimen consisted of a fibrocalcereous wall enclosing turbid fluid and necrotic debris; microscopic examination showed that it was a degenerated hydatid. Operation is the only treatment and often it will primarily be an exploratory thoracotomy for an undiagnosed mass.

CYSTS OF THE HEART AND PERICARDIUM

Most hydatid cysts of the heart are primary, the embryo having reached the heart muscle through the coronary circulation. Natural cure may occur here as elsewhere through death and inspissation of the cyst and it may be found at autopsy in a person who has died of some unrelated condition. Apart from this, hydatid cysts of the heart may be curiously latent, and there have been many cases of sudden death from rupture of an unsuspected cyst. Cardiac hydatids are as amenable to surgery as cysts elsewhere, and with the increasing use of mass radiography more and more should be discovered before serious complications occur. Two successful operations have been reported recently.^{5, 6} If left alone the cyst usually ruptures into the pericardium or into a heart chamber.

Rupture Into the Pericardium.—This may cause sudden death. If the patient survives he will suffer from severe pain, dyspnea, shock, and anaphylaxis; and if he recovers from this stage, heart failure may develop from the mechanical effects of the hydatid fluid, secondary effusion and, still later, of daughter cysts.

The primary cyst in the heart may involute or become the seat of daughter cysts. If operation is not done immediately, rupture of daughter cysts may cause a repetition of the same story.

Rupture Into a Heart Chamber.—If the patient does not die at once he will suffer from shock and anaphylaxis. As a rule he will recover from this and have another latent period. If the cyst was fertile, scolices, and brood capsules will have been carried in the blood stream to distant parts and some of these will probably grow into daughter cysts, the location of which depends on whether the rupture occurred into the right side or into the left side of the heart.

Rupture Into the Right Side of the Heart.—Scolices and brood capsules reach both lungs and some will develop into daughter cysts; it is characteristic that they are multiple, bilateral, and peripheral (Fig. 11).

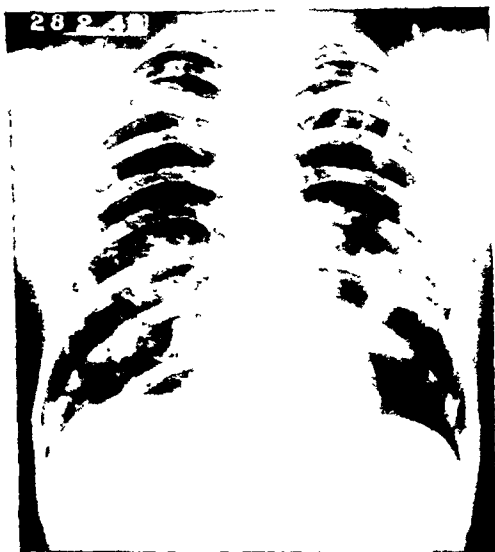


Fig. 11.—The subject of this film collapsed suddenly. During recovery he developed an urticarial rash, and hydatid tests were positive. No hydatid elements could be isolated from the patient and no primary cyst could be discovered. This film was taken three years after collapse. Five cysts have been removed from the left lung and he has since coughed up hydatid material. There are at least three cysts in the right lung. This story is characteristic of intravascular rupture of a hydatid cyst.

Rupture Into the Left Side of the Heart.—Metastatic cysts occur in peripheral organs and the brain is the main sufferer, but the liver, spleen, and kidney are also frequently affected. Many of these patients die from the cerebral complications. If the patient survives these catastrophes, daughter cysts will probably have developed in the primary cardiac cyst as a result of the rupture. At any time this may again break through to a heart cavity and the patient will probably die from acute anaphylaxis or from widespread embolism of daughter cysts.

HYDATID CYSTS OF THE LIVER

Even very large cysts of the liver, if they are still simple, may be latent and often an abdominal tumor is found by chance or during a routine examination,

Sometimes they cause symptoms by their very weight and size, but as with cysts elsewhere symptoms usually mean that complications have occurred, due to rupture of the cyst.

The rupture may be (a) into the biliary system, (b) into the peritoneal cavity, (c) into the thorax, and (d) less commonly into the vascular system, the alimentary tract, or the urinary system. These types of rupture may occur alone or in combination. A common combination is intrabiliary with intrathoracic rupture.

A large hepatic cyst situated immediately under the diaphragm is of particular interest to the thoracic surgeon: 1. It may be mistaken for a pulmonary cyst. A very large cyst may so thin out the stretched diaphragm that the possibility of it being an hepatic cyst is not considered. 2. It may simulate a pleural effusion and be aspirated, with serious results. 3. It may provoke a secondary pleural effusion. A pulmonary cyst rarely does so. 4. Apart from an effusion, it may compress the lung. 5. Bulging of the lower part of the chest is more common with a hepatic cyst than with a pulmonary cyst. 6. A large hepatic cyst, especially if it is in the left lobe, may cause displacement of the heart. 7. An hepatic cyst may rupture into the thorax with disastrous results. The rupture may occur into (a) the pericardium or mediastinum, (b) the lung and bronchial tree, or (c) the pleural cavity.

Before rupturing into the thorax the cyst has already probably ruptured into the biliary tract, leading to daughter cyst formation and pyogenic infection. There will, therefore, usually be a combination of abdominal and thoracic manifestations. The former occur first and vary from slight digestive disturbances to epigastric pain with jaundice and enlargement of the liver. The thoracic manifestations vary with the site of rupture and the kind of rupture. Involvement of the pericardium and mediastinum is rare and only the far commoner rupture into the lung and pleural cavity will be considered.

Primary Rupture Into the Pleural Cavity Without Involvement of the Lung.—This is rare because usually by the time that the final rupture occurs the diaphragm has become firmly adherent to both the liver and the lung. The symptoms are a sudden tearing pain, with dyspnea and anaphylactic shock from which the patient may die. If he recovers he will soon show evidence of pleural irritation and infection, and the withdrawal of bile-stained pus with or without hydatid elements clinches the diagnosis. As a rule, involvement of the pleura is secondary to the lung disruption caused by intrabronchial rupture of the cyst.

Intrabronchial Rupture.—This may come about in several ways: 1. The commonest way is direct spread to the bronchus by the shortest route through the lung substance. 2. The hepatic cyst may first lead to a pulmonary abscess before finally communicating with the bronchial tree. 3. The first intrathoracic complication may be an empyema and this may result in a bronchopleural fistula secondarily. 4. The hepatic cyst may cause a subphrenic abscess and this may later break into a bronchus, either directly through the lung or through the medium of an empyema.

It must be emphasized that a hepatic cyst that ruptures into the thorax has probably already ruptured into the bile ducts and is the seat of daughter cysts and secondary infection. The rupture into a bronchus usually results in pain and the expectoration of bloody bilious pus with hydatid material which may be too disorganized to be recognized by the naked eye. Anaphylactic symptoms are common at this stage and may be repeated as fresh eruptions into the bronchus occur. Because rupture into other parts may complicate rupture into the bronchus and because the rupture into the bronchus itself may follow various courses, symptoms and signs follow no set pattern.

A provisional diagnosis of intrathoracic rupture of an hepatic hydatid can often be made by remembering its possibility, by correctly interpreting anaphylactic manifestations, and by clinical, biologic, and radiologic examinations. A certain diagnosis is made by finding hydatid elements in the patient's discharges.

Daughter cysts are so much commoner in hepatic than in pulmonary cysts that if they are found in the sputum an hepatobronchial communication should at once be assumed. If bile also is found in the sputum all doubt is ended. Should sputum examination prove unfruitful a certain diagnosis may be made by the finding of hydatid material in the duodenal washings or in the feces, which is indicative of the intrabiliary rupture that so commonly precedes or accompanies the intrathoracic rupture.

TREATMENT OF HYDATID CYSTS OF THE LIVER

All hepatic cysts except dead and calcified ones should be operated upon as soon as possible and preferably before the onset of complications. The parasitic elements only should be removed, as attempts to excise the pericyst as well may result in disastrous hemorrhage; this is in contrast to a pulmonary cyst which can, as already stated, be safely removed with its pericyst if necessary.

Simple cysts and cysts with intra-abdominal complications are best approached through the abdomen. My preference is for an oblique incision starting near the navel and passing upward and outward over the costal margin which may be divided, without opening the pleural cavity, if better access is required. A thoracic or thoracoabdominal approach is reserved for simple cysts not accessible through the abdomen, and for cysts that have ruptured into the thorax.

TREATMENT OF SIMPLE CYSTS

All precautions are taken against soiling, the cyst is punctured, formalin may be injected, and then as much fluid as possible is aspirated; the pericyst is opened and the membranes and any remaining fluid are removed. If there is any leakage of bile, drainage is essential; but often the pericyst can be closed with safety; it should be stitched to the abdominal wall in case it should need reopening. I have turned the omentum into the cyst space and this has proved its worth.

TREATMENT OF CYSTS WITH INTRA-ABDOMINAL COMPLICATIONS

The commonest of these complications is rupture into the biliary tract and this must be discussed because of its frequent association with intrathoracic

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Daughter cysts are so much commoner in hepatic than in pulmonary cysts that if they are found in the sputum an hepatobronchial communication should at once be assumed. If bile also is found in the sputum all doubt is ended. Should sputum examination prove unfruitful a certain diagnosis may be made by the finding of hydatid material in the duodenal washings or in the feces, which is indicative of the intrabiliary rupture that so commonly precedes or accompanies the intrathoracic rupture.

TREATMENT OF HYDATID CYSTS OF THE LIVER

All hepatic cysts except dead and calcified ones should be operated upon as soon as possible and preferably before the onset of complications. The parasitic elements only should be removed, as attempts to excise the pericyst as well may result in disastrous hemorrhage; this is in contrast to a pulmonary cyst which can, as already stated, be safely removed with its pericyst if necessary.

Simple cysts and cysts with intra-abdominal complications are best approached through the abdomen. My preference is for an oblique incision starting near the navel and passing upward and outward over the costal margin which may be divided, without opening the pleural cavity, if better access is required. A thoracic or thoracoabdominal approach is reserved for simple cysts not accessible through the abdomen, and for cysts that have ruptured into the thorax.

TREATMENT OF SIMPLE CYSTS

All precautions are taken against soiling, the cyst is punctured, formalin may be injected, and then as much fluid as possible is aspirated; the pericyst is opened and the membranes and any remaining fluid are removed. If there is any leakage of bile, drainage is essential; but often the pericyst can be closed with safety; it should be stitched to the abdominal wall in case it should need reopening. I have turned the omentum into the cyst space and this has proved its worth.

TREATMENT OF CYSTS WITH INTRA-ABDOMINAL COMPLICATIONS

The commonest of these complications is rupture into the biliary tract and this must be discussed because of its frequent association with intrathoracic

rupture. Treatment must embrace the cyst itself and possible obstruction of the ducts with hydatid matter with or without cholangitis. As a rule the complete removal of the mother cyst and all daughter cysts will suffice, but sometimes it is necessary to remove debris from the bile ducts and drain them. The removal of innumerable daughter cysts may be a tedious and heartbreaking operation, and it is not uncommon for more daughter cysts to drain away for many weeks or months afterward.

TREATMENT OF INTRATHORACIC RUPTURE

Occasional cure by expectoration has been reported but this is very rare and operation is necessary for toxemia, hemoptysis, infection of the lung and pleura, and for the hepatic cyst itself.

The approach is primarily through the chest and diaphragm, with extension into the abdomen if necessary. Here one is dealing with a multivesicular infected cyst and more than one operation may be necessary to cure it and the thoracic extension. The pulmonary lobe may have to be removed if it is seriously damaged. On the other hand, evacuation and drainage of the cyst may suffice to close a less complicated hepatobronchial fistula. If the cyst is calcified drainage may continue indefinitely.

HYDATID CYSTS OF THE SPLEEN

Primary cysts of the spleen are comparatively rare and are usually associated with cysts in the liver and lung. They may come into the field of the thoracic surgeon because of bulging of the chest, pressure erosion of ribs, raising of the diaphragm, pleural effusion, compression of the lung, displacement of the heart, or rupture into the left lung or pleural cavity. The treatment for intrathoracic rupture aims at removal of the cyst contents and drainage of contaminated areas. Because the spleen is ductless, suppuration before rupture is very uncommon, in contrast to the sequence in hepatic cysts. Splenectomy greatly increases the operative risk and is rarely necessary. The need for lobectomy is even rarer.

HYDATID CYSTS OF THE KIDNEY

Primary cysts are as rare in the kidney as in the spleen but are more prone to daughter cyst formation and infection because of rupture into the urinary channels. A cyst in the upper pole may involve the diaphragm, pleural cavity, and lung (especially on the left side). If the cyst breaks through to the bronchus and to the urinary channels, hydatid elements may be found in the urine and sputum; the sputum may contain urine. The principles of treatment are the same as for intrathoracic rupture of other cysts and the surgeon may have to decide what to do as he goes along. Because of the urinary contamination and secondary infection, he should remove the kidney if possible, but he may only be able to remove as much hydatid material as possible and drain the involved areas.

CONCLUSIONS

This paper is based on a personal series of seventy-eight hydatid cysts (sixty-six pulmonary, ten hepatic, one diaphragmatic, and one probable cardiac).

Some of the general features of hydatid disease are discussed. Cysts of the lung and heart most closely touch the thoracic surgeon but abdominal cysts with thoracic complications may also fall to his lot. Methods of diagnosis and principles of treatment are discussed. The great tragedy is that this easily preventable disease is still prevalent.

I have to thank my colleagues for some of the patients and some of the case records. I also wish to thank the clinical photographers of three hospitals for copies of radiograms.

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DISCUSSION

DR. H. BRODIE STEPHENS, San Francisco.—Recently we have had occasion to see an annular density in the left lower lobe of a lady in the middle thirties. This abnormality was picked up on a routine screening examination. This mass resembled somewhat a bronchial cyst in the hilar area of the left lower lobe, and the chest x-ray film demonstrated that the abnormal area was lined by calcium. I should appreciate hearing Dr. Susman's comments in regard to the possibility of echinococci disease producing such a picture in the roentgenograms.

Bronchoscopic examination in this patient was negative. Exploratory thoracotomy revealed that the cystlike structure was located within the hilus of the left lower lobe. The wall of the mass was composed of a thin shell of calcium and the lumen of the cyst was filled with fresh blood. In order to remove the cyst it was necessary to perform a left lower lobectomy. The lumen of the cyst appeared to be a continuation of a portion of the lumen of the pulmonary artery to the lower lobe.

The diagnosis would appear to rest between aneurysm of the pulmonary artery or some type of complicated cystic disease of the lung. I should appreciate very much hearing Dr. Susman's comments with regard to this case, and to learn if he has encountered such a finding as a complication of hydatid disease of the lung.

DR. FREDERICK G. KERGIN, Toronto.—On this continent this disease is quite rare, and we are grateful to Dr. Susman for sharing his great experience with us. In Toronto, the disease is exceedingly rare in the lung, but of recent years we have seen a certain number of cases among displaced persons, emigrants. One of these cases was certainly unusual.

(Slide.) This 45-year-old man had come from Rumania and for three weeks had had hemoptysis. He had a positive Casoni test and increased eosinophiles, so we had a definite diagnosis. At operation there was considerable pneumonitis in the area of the lower lobe occupied by the cyst. We thought it was not suitable for local conservative resection and performed lobectomy.

(Slide.) This shows the cyst lying in the lobe and one can see the inflammatory change in the lobe.

(Slide.) The unusual feature of this case appears to be that this cyst lies in the posterior basic bronchus. You can see that the bronchial wall is just outside the cyst. So the cyst occupies the posterior basic bronchus and has enlarged to cause tremendous ectasia of the bronchus.

I should like to ask Dr. Susman if this is a recognized form of the pathology of the disease.

DR LOUIS R DAVIDSON, New York—Nine years ago I presented before this Association a paper entitled "Hydatid Cysts of the Lung"; it was based upon a personal experience with four cases. Since very few patients with this disease of the lungs are seen in the United States, you will agree with me, I am certain, when I say that it is bordering upon arrogance for a North American surgeon to discuss a substantial presentation such as that which you have just heard from Dr Susman. It is with great hesitancy therefore that I discuss this subject.

In any event, having studied the literature, particularly as related to complicated cysts, I shall present to you the x ray sign which permitted me, in one case, to make an unequivocal preoperative diagnosis of hydatid disease of the lung. A pathognomonic x ray sign is noted only when the cyst becomes complicated and strange as it may seem it is complicated only when the adventitia is involved.

(Slide) This, the outer layer of the hydatid vesicle, is the laminated layer. The inner portion is the germinal layer. It is obvious that there is a difference between a hydatid vesicle and a hydatid cyst. The latter is a hydatid vesicle plus the adventitia which is the perivesicular layer which is laid down by the host organ in which the vesicle resides. Within the vesicle when it is not biologically sterile scolices, hydatid sand, and hydatid fluid (aqua roca) are found.

With the aid of this lantern slide I shall attempt to indicate to you the evolution of the condition which permits of an absolute preoperative diagnosis. The cyst wall impinges upon a bronchiole. Finally the adventitial layer is eroded by this bronchiole and air escapes from the tracheobronchial tree between hydatid vesicle and the adventitia, thereby encircling the vesicle. This produces a "perivesicular pneumonia." Now, if in turn the layers rupture, air gets into the vesicle itself and produces what is known as a "double domed arch." Finally, when the membrane sinks onto the fluid this condition, as represented in the slide, is known as the camolote formation. One of Dr Susman's slides showed this radiographic evidence of this complication.

Therefore, with this description of the evolution of a complicated cyst being kept in mind, I should like to show you one case in which I was able, by good fortune, to make the preoperative diagnosis of a hydatid cyst of the lung. (This patient was seen at the U S Marine Hospital, Stapleton, Staten Island.) Varying diagnoses were made but fortunately, having learned from the literature of this radiographic sign of complicated hydatid cyst, the diagnosis was made preoperatively. Later when I operated the diagnosis was substantiated both macroscopically and microscopically.

It was a pleasure indeed to discuss Dr Susman's most interesting and illuminating paper.

DR RICHARD H MEADE, Grand Rapids—Dr Susman mentioned the danger of dissemination of the disease from spilling the contents of the cyst when it ruptures. It has been my impression, from reading, that in a great many cases when a cyst was opened inadvertently, an allergic reaction might occur. In 1931, in Philadelphia, I believe, Dr Phillips of Rochester gave a paper on this subject and pointed out that infestation with this hydatid was much more common in this country than we had realized. Two years later I assisted Dr Raydin in an operation on an echinococcus cyst of the mediastinal pleura and, not suspecting the nature of it, the cyst was ruptured, and the pleural cavity was inundated with the fluid. The patient made a completely uneventful recovery and has been well since so far as I know.

I would like to ask Dr Susman if the impression I have of the danger of an allergic reaction is correct.

DR AUSTIN H BELL, Oklahoma City—I should like first to thank the Association for the privilege of the floor. Second, I wish to thank Dr Susman for this paper, and also I wish to thank him and his fellow Australians who were of such help to us during the past war. Those of us who were at that time in the South Pacific remember quite gratefully their efforts in relieving us in our island hopping campaigns in that area.

Third, we had at Ft. Benning, Ga., in the regional hospital, an Italian prisoner of war who presented himself, as in Dr. Davidson's case, with the diagnosis made when we saw him in consultation. The cyst had been aspirated by the medical service, under the impression that it was an amebic abscess. It was a large cyst of the dome of the liver, aspirated through the chest. We felt that it presented an emergency. It was approached transthoracically and, as Dr. Susman suggested, unless one wishes to get into a tremendous hemorrhage, these cysts must be removed from the compressed zone of the liver without attempting to remove the compressed zone of liver. During the exploration two additional cysts were noted, one in the anterior lobe on the right side, and one in the left lobe of the liver. These were later handled transabdominally, satisfactorily.

I would like to ask Dr. Susman whether the use of formalin, as suggested previously by older authors, had any additional value. Older authors suggested aspiration of the cyst, the injection of formalin, a weak solution, into the cyst, a wait of five or six minutes, and packing the surrounding area off with packs soaked in weak formalin solution.

The nearest description I can give of these membranes in the liver itself, is that of a football in which the bladder is collapsed. We lift it out intact; a catastrophic hemorrhage will occur if an attempt is made to remove the zone of compressed liver.

DR. LEO ELOESSER, San Francisco.—A short stay in the Argentine, in Buenos Aires, convinced me of the superiority of resection, that is, removal of the cyst, as against the old methods of drainage and formalinization known to the South American continent as the method of Posada.

I should like to ask Dr. Susman how accurate are the skin tests and complement fixation tests in the diagnosis of this disease. The disease is not entirely rare in California; it occurs among the Basque shepherds of the Sierra Nevadas not too infrequently.

DR. ELLIOTT HARRISON, Vancouver.—I think this is a most appropriate paper, as I think we will probably see more of this disease in the near future than we have in the past. In British Columbia we had the first case of echinococci cyst of the lung in 1948. I reviewed the cases admitted to the Vancouver hospitals for ten years prior to that (from 1938 to 1948) and there was not one case recorded in the two hospitals, which aggregate approximately 1,800 beds. Since that time we have had eleven cases of echinococci cyst of the lung and I believe we will see more, because a recent review of the animals in northern British Columbia by the Canadian government has revealed a large percentage of infection among dogs and among wild animals such as moose and elk.

(Slide.) This represents the distribution of our first seven cases. You will note that they are all in the northern part of the province. Since then there have been three further cases, farther north than shown on this map. The eleventh case is a patient who was infected in Australia. Of the eleven cases, ten have been among North American Indians and two in whites—the one who was infected in Australia and the other a young boy who lived in northern British Columbia.

(Slide.) This is a typical case as shown in our series. They have been treated in a manner similar to that described by Dr. Susman. There have been eleven operations, five with removal of the cyst, two lobectomies, and the remainder wedge resections. In two cases the cyst was ruptured but there have been no untoward results. There was no mortality, and all patients are well.

The next slides show some of the cysts which have been removed, and cases in which lobectomy was done.

I would like to ask Dr. Susman if he places any reliability on the Casoni test and also on the eosinophile count.

DR. GABRIEL SELEY, New York.—Having had experience with two echinococcus cysts of the lung, I was alert in looking for a third. A patient presented herself with a cystlike structure occupying almost the entire right lower lobe. She unfortunately had the pathognomonic sign that has just been described by Dr. Davidson. However, there was nothing else about her history to suggest echinococcus disease. In searching further it was found that she had had a rather severe pneumonia one year prior to this admission. At

operation the entire right lower lobe was found to be replaced by a large cystlike mass, and a lower lobe lobectomy was performed. The pathology consisted of a chronic burnt-out huge lung abscess and the contents of the cyst consisted of pure fungi without evidence of usual bacteria.

In reconstructing this case it appeared that this patient had a chronic lung abscess and the cavity filled with fungi after the pathogenic bacteria had been killed off by antibiotic therapy. The pathognomonic sign that is supposed to indicate echinococcal disease can and does occur in this condition. In fact, any cystic cavity which is almost completely filled with debris, blood clot or inspissated material can produce the same roentgen sign.

DR. SUSMAN (Closing).—Bronchoscopy as a rule is not helpful in hydatid disease but I have once made the diagnosis thus in a patient who had a ruptured hydatid cyst; I saw what I thought to be a foreign body in the bronchus and it turned out to be a piece of hydatid membrane. In another case a colleague removed what was left of the hydatid cyst and the patient made a recovery without operation.

Hemorrhage in any operation for hydatid cyst may occur unexpectedly in the lung as well as in the liver and may be one of the rare occasions in which lobectomy might have to be done for a simple cyst. It is very rarely, however, that it is necessary, because if the hilum is temporarily controlled with the finger the bleeding points can generally be found. Cysts of the lung can calcify as Dr. Stephens said, but I have never seen so thick a layer on a lung cyst. I would doubt if his patient had had a hydatid cyst unless the hydatid tests were positive.

Dr. Kergin found inflammatory changes in the surrounding lung. They do occur but they are not irreversible, and I have been impressed by the fact that the surrounding lung recovers remarkably well and I repeat that, with rare exceptions, conservative surgery and not radical surgery is the correct procedure. Bronchiectasis is quite common and in a recent survey of the Hydatid Registry of some 500 cases in New Zealand and Australia quite a number had symptomless bronchiectasis found on bronchography. Most of the patients were followed for a long time and did not require further surgery.

I am not quite in agreement with Dr. Davidson. A complicated cyst is one that has ruptured and probably, though not inevitably, has become secondarily infected. There may be no change whatever in the pericyst (the adventitia) or surrounding lung. That is a usual finding, I would say, even in infected cyst.

Dr. Meade brought up the point of anaphylaxis. It is common; in fact the immediate serious symptoms following rupture are almost always due to anaphylaxis, and they may be repeated every time a cyst reruptures or if the patient is submitted to operation. Mediastinal hydatid cysts are rare. I have seen none, and I suggest that the one Dr. Meade had was in the pleural cavity although it might have seemed to be in the mediastinum.

Dr. Bell's resident aspirated one case, and that is a dangerous thing to do. Patients have died suddenly or have suffered severely from anaphylaxis and have sometimes ended up later with multiple daughter cysts.

Formalin I did not mention. There is a tendency in Australia now not to regard it as absolutely necessary and one certainly should not use it in a lung cyst because there is always a bronchial fistula and the patient may suffer from its irritation.

The various hydatid tests and their significance are discussed in the body of my paper.

SURGICAL CONSIDERATIONS IN FOCALIZED PULMONARY HISTOPLASMOSIS

COLONEL JAMES H. FORSEE, MAJOR THOMAS F. PUCKETT (BY INVITATION), AND
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SINCE February, 1951, the diagnosis of focalized pulmonary histoplasmosis has been made on thirty patients following surgical exploration of the hemithorax and the histopathologic examination of excised pulmonary and mediastinal lesions. Except for one case the diagnosis was based solely on the morphologic characteristics of *Histoplasma capsulatum* demonstrated in the excised tissues employing the periodic-acid-Schiff (P.A.S.) stain.¹

For years following Darling's original report in 1906, histoplasmosis was considered a generalized and frequently fatal disease. At that time he suggested the name *Histoplasma capsulatum* for certain intracellular "protozoa" he noted in tissues from a human autopsy he had performed in Panama.² In recent years evidence indicates that histoplasmosis is a frequently encountered fungus disease often manifested in the lungs. It is rather common in a benign form.³⁻⁵ Our interest developed as a result of considerable experience in the surgical management of round pulmonary lesions such as the tuberculoma and coccidioidoma.^{6, 7} As the focalized pulmonary lesions of histoplasmosis have become recognized there has been a marked decline in the incidence of pulmonary lesions classified as tuberculomas in which the tubercle bacillus was not demonstrable.

CASE REPORTS

CASE 1.—This 36-year-old white airman had been in the Regular Army or Air Force for twelve years; he had lived in Texas five years and abroad in England, Germany, and the Philippine Islands for three years. A re-enlistment chest roentgenogram in May, 1950, revealed a round, discrete, 2 cm. area of increased density in the right lower lung (Fig. 1). Extensive clinical investigation revealed no evidence of active pulmonary tuberculosis or neoplastic disease. In July, 1952, he complained of chest pain and cough with an unexplained weight loss of thirty-four pounds during the previous six months.

He had regained seventeen pounds by November, 1952, when he was admitted to Fitzsimons Army Hospital. He was asymptomatic. Chest roentgenogram revealed the findings previously described. The skin test revealed a two plus P.P.D. No. 1 and histoplasmin 1:1000 was one plus. Coccidioidin was negative. Repeated examinations of the sputum were negative for acid-fast bacilli and fungi. Bronchoscopic examination was negative. On December 19, a right thoracotomy revealed a free pleural space and no hilar lymphadenopathy. There was a 2 cm., firm, round, discrete nodule located beneath a thick pleural plaque in the anterior inferior portion of the right lower lobe. The remainder of the lung was normal. This nodule was removed by wedge excision.

From the Surgical and Laboratory Services, Fitzsimons Army Hospital, and the Department of Surgery, University of Colorado School of Medicine

Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 30, 1953.

The cut surface of the nodule revealed a dense fibrous wall, a laminated peripheral area, and a soft center (Fig. 2). Microscopically there was an encapsulated focus of coagulative pneumonitis with a necrotic center. *Histoplasma capsulatum* was identified in the necrotic material (Fig. 3). Smear and culture of the excised tissue were negative for acid-fast organisms. The patient made an uneventful recovery and has continued on full military duty.



Fig. 1—Rounded area of increased density in right lower lung field (Case 1)

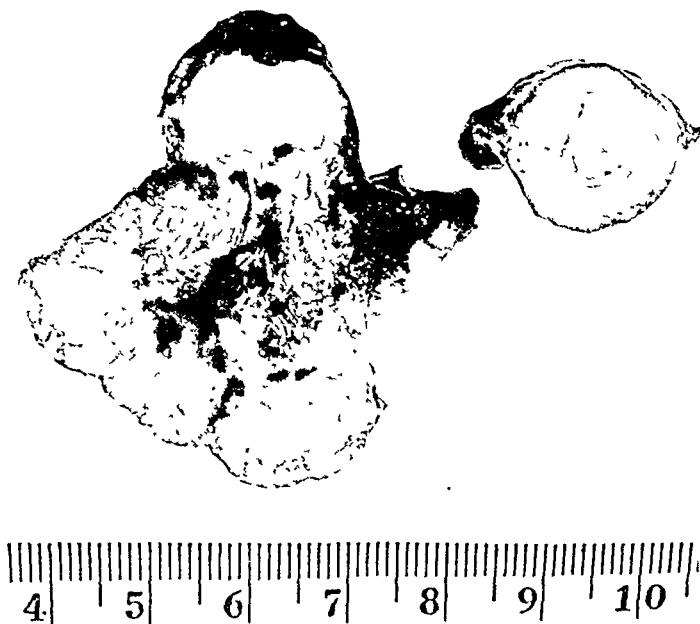


Fig. 2—Surgical specimen Pleural plaque and laminated appearance of lesion demonstrated (Case 1).

CASE 2.—A 20 year-old soldier was admitted to Fitzsimons Army Hospital July 21, 1951, after a duty tour of twenty six months in Panama. A routine chest roentgenogram had disclosed a 3 by 4 cm. cavitory lesion in the apex of the left upper lobe (Fig. 4). Nothing abnormal was detected on physical examination. Smears and cultures of sputum and gastric contents were repeatedly negative for *M. tuberculosis* and fungi. Complement fixation for

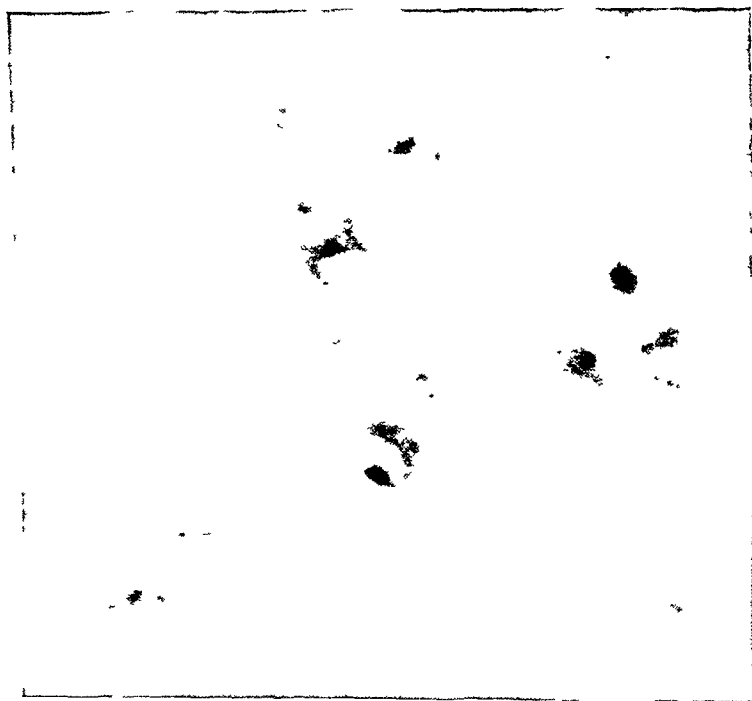


Fig 3 (Case 1).—*Histoplasma capsulatum* in central portion of lesion (P.A.S. stain, $\times 2000$).

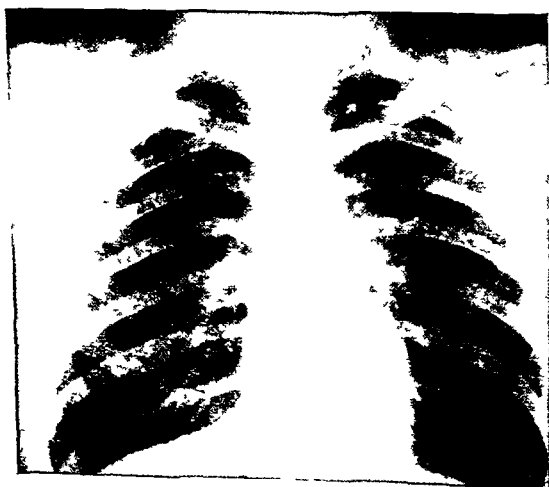


Fig 4 (Case 2).—Cavitory lesion in left upper lung field.

histoplasmosis was positive in 1:20 dilution and negative for coccidioidin. Bronchoscopy was negative. The tuberculin skin test was positive as was the histoplasmin skin test while the coccidioidin was negative.

Four months of bed rest, streptomycin, and para aminosalicylic acid therapy resulted in no appreciable change in the cavity lesion. On November 21, 1951, surgical exploration of the left thoracic cavity revealed dense adhesions between the left apex and the parietal pleura. These were severed. A firm nodular area, approximately 4 cm. in diameter, was palpable in the apicoposterior area and resection of that segment was accomplished. The specimen contained a 3 by 1 by 1.9 cm. thin-walled cavity containing yellowish necrotic material. No bronchial communication could be demonstrated (Fig. 5).

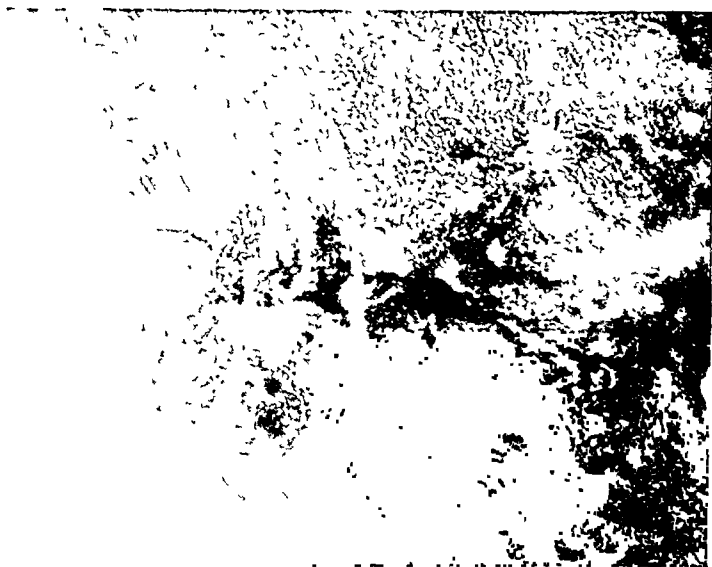


Fig 5—Surgical specimen (Case 2) Cavity, left upper lobe

Microscopically the cavity was seen to be composed of a dense wall of fibrous tissue and was partially lined by bronchial epithelium. Accumulations of lymphocytes, epithelioid, and giant cells were seen peripherally. The central area was composed of amorphous granular material containing large mononuclear cells. Organisms morphologically identified as *Histoplasma capsulatum* were seen within monocyte cells of the cavity wall. A fungus was cultured on brain heart infusion (BHI) media and intraperitoneal inoculation of a suspension into mice produced histoplasmosis in the animals with typical intracellular organisms in the liver and lungs.

The age variation of the patients was from 20 to 48 years; twenty-eight were men and twenty-nine were Caucasians. It is of interest to note that 40 per cent had resided in Panama (Table I).

The divergence of opinion regarding the significance of the histoplasmin skin test is not clarified by our case material.⁸⁻¹¹ The results of the skin tests are shown in Table II. The negative reactor unfortunately did not have the test repeated.

Complement fixation tests and collodion agglutination tests were performed by the Army Research and Graduate School, Washington, D. C., on eighteen patients and the results are shown in Table III. The positive reactors with the highest titers were those in whom there was histologic evidence suggestive

TABLE I. AGE, RACE, SEX, PLACE, AND LENGTH OF RESIDENCE

AGE	RACE	SEX	RESIDENCE
29	W	M	Tennessee—2 yr.
43	W	M	Africa—2 yr.
26	W	M	Minnesota—18 yr.
27	W	M	Illinois—20 yr.
26	W	M	Iowa—20 yr.
28	W	M	Panama—2 yr.
27	W	M	Panama—2 yr.
34	W	M	Nebraska—20 yr.
31	W	M	Panama—2 yr.
20	W	M	Panama—2 yr.
23	W	M	Panama—3 yr.
46	W	M	Missouri—1 yr.
30	W	M	Panama—3 yr.
40	W	M	Panama—2½ yr.
27	W	M	Alabama—15 yr.
31	W	F	Nebraska—10 yr.
35	W	M	Kansas—2 yr.
33	W	M	Panama—3 yr.
33	W	M	Nebraska—2 yr.
34	W	M	Tennessee—3 yr.
39	W	M	Panama—2 yr.
24	W	M	Panama—3 yr.
42	W	M	Panama—2 yr.
21	W	M	Tennessee—15 yr.
24	W	F	Panama—2 yr.
48	W	M	Tennessee—1½ yr.
29	W	M	Kentucky—1 yr.
21	W	M	Missouri—20 yr.
36	W	M	Texas—5 yr.
34	W	M	Panama—5 yr.

TABLE II. RESULTS OF INTRADERMAL TESTS

H	C	T ₁	T ₂	CASES
+	±	—	—	3
+	+	—	—	3
±	±	±	—	4
±	—	—	±	7
±	—	±	—	6
—	—	—	—	6
—	—	—	±	1
Total				30
H±	Histoplasmin positive		H—	Histoplasmin negative
C±	Coccidioidin positive		C—	Coccidioidin negative
T ₁ ±	P. P. D. 0.00002 mg. positive		T ₁ —	P. P. D. 0.00002 mg. negative
T ₂ ±	P. P. D. 0.005 mg. positive		T ₂ —	P. P. D. 0.005 mg. negative

TABLE III. RESULTS OF COMPLEMENT FIXATION AND COLLODION AGGLOUTINATION TESTS

HISTOPLASMA COLLODION AGGLOUTINATION	HISTOPLASMA COMPLEMENT FIXATION	COCCIDIOIDES IMMITIS COMPLEMENT FIXATION
Negative	Negative	Negative
Negative	Negative	Negative
Positive 1:10	Negative	Negative
Negative	Positive 1:20	Negative
Negative		
Negative	Positive 1:20	Negative
Negative	Negative	Negative
Negative	Positive 1:5	Negative
Negative	Positive 1:5	Negative
Positive 1:20	Positive 1:10	Negative
Negative	Negative	Negative
Negative	Positive 1:5	Negative
Negative	Positive 1:10	Negative
Negative	Negative	Negative
Positive 1:5	Positive 1:5	Negative
Positive 1:10	Negative	Negative
Positive 1:20	Negative	Negative
Negative	Negative	Negative

of "activity" as manifest by greater lymphocytic and plasma cell infiltration, more numerous epithelioid tubercles, and less extensive fibrosis. It is the opinion of some who have had considerable experience in the use of these tests that a titer of 1:40 or above for the complement fixation indicates the presence of a mycotic infection.¹²

In this group of patients the symptoms were mild or absent. Fourteen of the thirty had no symptoms referable to the chest. In twelve the lesion was noted on a routine chest roentgenogram and in two the detection was made as a part of a study to ascertain the cause of epigastric distress. Among these, one patient had had roentgenographic evidence of the lesion for seven years and two patients had had roentgenographic evidence of lesions for four years. Sixteen patients had symptoms referable to the chest such as hemoptysis, productive cough, chest pain, and moderate loss of weight.

The roentgenographic findings were those of any other so-called round or ovoid density within the lung or mediastinum. Hilar densities 2 to 4 cm. in diameter were noted in five patients. A cavitory lesion was present in only one patient, and moderate bronchiectasis coexisted on the side of the histoplasmosis lesion in one patient.

Sputum smears and cultures of sputum and gastric washings were repeatedly negative for acid-fast bacilli in all but one patient in whom sputum smears were positive elsewhere but were repeatedly negative at Fitzsimons. Smears and cultures taken from the surgically excised tissue were negative for acid-fast bacilli in all patients. With the use of the P.A.S. stain, *Histoplasma capsulatum* was identified in the excised pulmonary or mediastinal lymph node tissue in all patients. Cultures for *Histoplasma capsulatum* were positive in only one patient.

Although this organism is fastidious in its growth requirements, an explanation for the inability to culture organisms from tissue other than the cavitory lesion in this series is not clear. Others have had difficulty in isolating the organisms from animals with experimental histoplasmosis.¹³ Fureulow¹⁴ is of the opinion that organisms in calcified lesions are probably not viable. Slight variations in the staining characteristics along with variations in the number, location, and morphology of organisms present in the healed or healing lesions in this series lead us to suspect that they are no longer viable.

Histoplasma capsulatum exists in two forms: (1) A yeastlike form found in infected tissues and (2) a mycelial form, presumably the form existing in nature. In tissue the organism is round or ovoid, 3 to 5 microns in diameter with occasional crescentic forms. It is usually intracellular but is occasionally extracellular. With the P.A.S. stain it has a well-defined limiting membrane that is stained brilliant red or reddish-purple and a central mass that usually stains bright red but is occasionally dark blue. There is a clear zone between the central mass and the limiting membrane. Organisms were present throughout necrotic foci and occasionally were seen within the ghost outlines of alveoli. Often there were clusters of four to ten organisms with a suggestion of the

remnants of a cellular outline about them. Elsewhere single organisms were diffusely scattered. The use of this selective stain and the oil immersion lens are essential for identification.

The gross appearance of the pulmonary lesion was interesting. The pleural cavity in all patients was free of fluid. Adhesions were absent in most instances and of significance only in the one patient with a cavitory lesion. The lesions were circumscribed and solitary in eleven patients. The remainder contained two or more satellite lesions close to, or some distance from, the main nodule. A plaque was commonly seen on the visceral pleura overlying the nodular lesion and the pleura was often thickened and puckered. The consistency varied from firm or semifluctuant to hard and rubbery. The cut surface often revealed concentric laminations and the typical lesion was yellowish-gray to grayish-white with a small central or eccentric yellowish necrotic focus. A well-defined fibrous capsule enclosed material which was semifluid, friable, rubbery, or hard. None were calcified although flecks of calcium were frequently noted microscopically. In general, the lesions were indistinguishable from similar granulomas due to *M. tuberculosis* and *Coccidioides immitis*.

The microscopic examination of the nodular lesions revealed a fibrous capsule which was often hyalinized. Accumulations of lymphocytes, epithelioid cells, and occasional giant cells were adjacent to or within the capsule. Rarely a bronchiole was seen in close association with the capsule. Central coagulative necrosis was present in which ghost cell outlines and alveolar walls were often evident. Areas of necrosis were sometimes multiple, and adjacent epithelioid tubercles without central necrosis were occasionally seen. Adjacent pulmonary tissue presented patchy atelectasis and varying degrees of perivascular and peribronchiolar fibrosis. There were foci of organizing pneumonia adjacent to the cavitory lesion.

Puckett⁵ has separated the pulmonary lesions into four groups: (1) focal encapsulated pneumonitis without satellite lesions, (2) focal encapsulated pneumonitis with smaller satellite lesions, (3) focal encapsulated pneumonitis with extensive involvement of the lymphatic channels, and (4) cavitory lesions.

Enlargement of hilar nodes was not commonly observed during surgical exploration of the chest for parenchymal lesions. In three patients moderately enlarged hilar lymph nodes were removed which contained *Histoplasma capsulatum*. The lung tissue was not involved. In two patients both lung and lymph nodes were involved.

CASE REPORT

CASE 3.—This 34-year-old white male officer spent most of his life in Nebraska and was in Korea for fourteen months prior to hospitalization in October, 1951, following the detection of a circumscribed 3 cm. area of density in the left lung field. He was asymptomatic. Physical examination was negative. Bronchoscopy was negative. Skin tests were as follows: P. P. D. No. 1 was two plus, coccidioidin one plus, and histoplasmin two plus. An exploratory thoracotomy was performed at Fitzsimons Army Hospital Nov. 9, 1951, and a 3 cm. subpleural, hard, rubbery, yellowish nodule with a moderately thick pleural plaque was removed. Three slightly enlarged, firm, mediastinal nodes were also removed (Fig. 6).

The lung nodule and lymph nodes contained *Histoplasma capsulatum* demonstrated by the P.A.S. stain. The interesting feature in this case is that the lesions may represent a

primary complex of histoplasmosis somewhat similar to the Ranke complex of primary tuberculosis. The organisms could not be grown on culture. He had an uneventful recovery and returned to military duty.



Fig. 6.—Parenchymal nodule and hilar nodes; necrotic areas present in nodes (Case 3)

The surgical management required pulmonary excision by wedge excision in twenty-three patients. Two had lesions excised from more than one lobe, two were treated by segmental resection, two by lobectomy (right middle lobe), and the excision of hilar lymph nodes alone led to the diagnosis in three patients. The side of the lung lesion removed was on the right in twelve instances and the left in fifteen.

SUMMARY

The focalized lesions of pulmonary histoplasmosis are often indistinguishable from neoplasm, tuberculoma, coccidioidoma, and other granulomatous lesions in their roentgenographic or gross appearance as well as clinical manifestations, and require surgical removal and histopathologic examination of the excised tissue for differentiation. The use of the periodic-acid-Schiff stain in the study of the excised tissue has greatly facilitated the identification of *Histoplasma capsulatum* and with the identification of these organisms there has been a steady decline in the number of lesions previously classified as tuberculoma but in which the tubercle bacillus could not be demonstrated. The inability to culture the organisms from the focalized lesions is probably due to their not being viable. The surgical excisions can generally be accomplished by wedge excision of the lung tissue containing the lesion. There has been no evidence to indicate that dissemination of the disease results from surgical removal of the focalized lesion. The recognition of histoplasmosis as a granulomatous pulmonary lesion often focalized and benign is a further aid in the diagnosis and therapy of the lesions within the lung and mediastinum, the nature of which cannot be ascertained without surgical exploration, removal of the lesion, and histopathologic examination of the excised tissue.

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BILATERAL BRONCHIECTASIS

A CLINICAL AND PHYSIOLOGIC EVALUATION OF THE RESULTS OF SURGICAL TREATMENT

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IN MANY of the published results of extensive lung resections for bronchiectasis, emphasis has been placed upon the incidence of such complications as hemorrhage, shock, bronchopleural fistula with empyema, and pulmonary infection with excessive secretions. Advances in the technique of hilar dissection and in anesthesiology, as well as the availability of antibiotics and whole blood transfusion have contributed to a declining incidence of such complications and consequently to both a lower operative and hospital mortality.

Bisgard¹ reported a death rate of 13.5 per cent in thirty-seven cases of bilateral resections for bronchiectasis collected from the literature. Lindskog² performed twelve bilateral resections without a mortality, and Kergin³ reported only four deaths in thirty-one bilateral resections, the last nineteen being done without loss of life. Our report is concerned chiefly with the late results following resections performed on thirteen patients with bilateral bronchiectasis, three of whom underwent pneumonectomy and ten of whom had bilateral resections. Although there was no operative or hospital death in our series, one patient died fifteen months and another thirty-four months after leaving the hospital, from causes related to surgery.

Our interest in the cardiorespiratory status of these patients has been stimulated for the following reasons:

There is a discrepancy in the reported incidence of dyspnea following pulmonary resection. There is no mention of dyspnea in any of the twelve patients who had bilateral resections in the series of Lindskog² although six of these patients had residual lesions. Kergin³ reported "remarkably little evidence of decreased respiratory function" in the eighteen of his patients with bilateral resection whose progress he was able to follow. No function studies were reported. In the series of Rosemond,⁴ 88 of 159 patients had some degree of dyspnea after resection of various amounts of lung tissue. Six patients, in whom the disease had been bilateral, were severely handicapped. Taylor, Roos, and Burford⁵ found that two of twelve patients with bilateral resections were

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unable to work because of severe dyspnea, and the remaining ten carried on their usual routine in a normal fashion but had some degree of dyspnea on exertion. Graham,⁶ after successfully resecting thirteen bronchopulmonary segments in 1941, asked the question "With how little lung tissue is life compatible?" The most extensive resection on human beings which we have been able to find in the literature is that of W. E. Adams.⁷ This patient had a resection of the right middle and lower lobes, the left lower lobe, lingula, and emphysematous lower tips of the remaining parts of the left and right upper lobes. He was described as being less dyspneic after operation than he had been in the preoperative period.

From the practical surgical point of view, we believe the following concepts, expressed by us in an earlier report,⁸ may be worthy of repetition:

Clinical experience and animal experimental contributions⁹⁻¹³ have only partially answered the question originally propounded by Graham. The age, general health, daily activity, and cardiorespiratory status of the patient are some of the influencing factors needing further evaluation.

The incidence of emphysema, ventilatory insufficiency with hypoxemia, pulmonary hypertension, and cor pulmonale following extensive lung resections should be clarified. The disadvantages of a state of respiratory insufficiency postoperatively must be weighed against not only the handicaps of the disease as they exist without operation but also against the amelioration of symptoms other than dyspnea following operation. In cases of bilateral disease a happy compromise may be found in some cases by resecting only one side even when the disease is fairly evenly distributed. While the series which we report is not large enough to be statistically significant, we believe the data will be helpful in directing attention to the problem of respiratory insufficiency following extensive lung resections.

The report encompasses the following groups of patients:

1. Three patients who have had pneumonectomy for extensive unilateral bronchiectasis, but who still have bronchiectasis in one segment of the remaining lung.
2. Ten patients who have had bilateral resections of from seven to thirteen bronchopulmonary segments.

METHODS

In evaluating our results clinically, we compared the frequency and severity before and after operations, of such signs and symptoms as productive cough, hemoptysis, chest pain, dyspnea, weight loss, fever, and attacks of pneumonia, pleural effusion, sinusitis, and respiratory infections. The roentgen evaluation includes standard posteroanterior and lateral views and fluoroscopy in all patients and postoperative bronchograms in four patients. The physiologic methods have been described by Cournand.¹⁴ The investigations have included fractionation of lung volumina, maximum breathing capacity, carbon dioxide and oxygen values of arterial blood, and exhaled gases at rest and following a standard one-minute exercise test. Cardiac catheterization using a water manometer was done in two patients, and in one patient the Sanborn double channel re-

corder was used. One patient had bronchspirometry. Patients were studied when the bronchial tree was relatively dry after a period of antibiotic therapy and postural exercises.

Abbreviations used in this report are listed:

M.B.C.	Maximum breathing capacity
VC	Vital capacity
IC	Inspiratory capacity
ER	Expiratory reserve
RA	Residual air
TC	Total lung capacity
Alv.N %	Alveolar nitrogen after seven minutes of oxygen breathing
MV	Minute ventilation expressed in liters per m.m ² B.S.A.
O ₂ Sat. %	Arterial oxygen hemoglobin saturation
CO ₂ V. %	Arterial carbon dioxide volumes per cent

GROUP 1. PATIENTS WITH PNEUMONECTOMY

Material.—The ages of the three men at the time of operation were 50, 36, and 25 years. All patients had clinically severe bronchiectasis with a chronic cough productive of from 60 to 240 c.c. of purulent sputum daily. One patient had suffered five attacks of pneumonia, two patients were considerably underweight, and one had had severe hemoptysis. The patients have been followed clinically for twenty-four to thirty-six months. Physiologic studies were done before operation and at intervals from nine to twenty-two months after operation.

Results.—The general health of the three patients is greatly improved. One patient is asymptomatic and the other two have an infrequent cough productive of not more than 8 c.c. of sputum daily. One patient is dyspneic on moderate exertion, but less so than before pneumonectomy (Table I).

TABLE I. PNEUMONECTOMY. BILATERAL BRONCHIECTASIS

	CASE 1, S. C., AGE 50		CASE 2, R. R., AGE 36		CASE 3, R. K., AGE 25	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Cough	Frequent 10 yr.	Infrequent	Frequent 30 yr.	0	Frequent 17 yr.	Rare
Sputum	60 c.c. purulent	8 c.c. clear	120 c.c. purulent	0	240 c.c. purulent	4 c.c. thick
Dyspnea	+++	++	0	0	0	0
Hemoptysis	0	0	1948	0	0	0
Respiratory infections	Very frequent	0	Frequent	0	Very frequent	0
Residual bronchiectasis	L. U. ant. segment Moderate		R. basal Mild		R. U. Ant. segment Moderate	

Results of the physiologic studies are given in Tables II and III, and may generally be summarized as follows:

1. A decrease in maximum breathing capacity, total lung capacity, inspiratory capacity, and expiratory reserve occurred in each patient. A 54 per cent

TABLE II. VENTILATORY STUDIES. PRE- AND POSTOPERATIVE PNEUMONECTOMY

PATIENT DATE OF OPERATIONS	DATES OF STUDIES	M.B.C.	TC	VC	IC	ER	RA	FRA	RA × 100 TC	ALV.N.
		PRE- DICTED								
Case 1, S. C. Right pneumonectomy 1/19/50	Preop.									
	1/12/50	88	4108	2390	1596	794	1718	2512	41	2.19
	P. O.	46								
	9/15/50	91	3115	1824	1036	788	1291	2079	41	2.00
Case 2, R. K. Left pneumonectomy 7/18/50	Preop.									
	7/ 3/50	93	4623	3358	1907	1451	1265	2716	27	3.05
	P. O.	82.5								
	3/20/51	129	3337	2280	1223	1057	1057	2114	31	1.37
Case 3, R. R. Left pneumonectomy 1/19/51	Preop.									
	1/16/51	98	5906	3876	2301	1575	2030	3605	34	4.24
	P. O.	85								
	11/14/52	123	4722	2943	1824	1119	1779	2896	37	1.51

reduction of the preoperative value in one patient (Case 1, S. C.) produced a maximum breathing capacity of only 51 per cent of the predicted normal, representing moderately severe ventilatory insufficiency.

2. Only one patient (Case 1, S. C.) had a significantly elevated residual air-total capacity ratio (41 per cent). This was unchanged by pneumonectomy.

3. The alveolar nitrogen after seven minutes of oxygen breathing was elevated in two of the three patients before pneumonectomy but was normal in all patients after operation, indicating improvement in intrapulmonary mixing of gases.

4. The patients after pneumonectomy had a low normal or slightly sub-normal resting and post-exercise arterial oxygen saturation, representing a marked improvement in exercise response for one patient (Case 1, S. C.) even though there was considerable loss in maximum breathing capacity. The improvement was due to the removal of a lung which was consuming only 4 per

TABLE III. EXERCISE RESPONSE PRE- AND POSTPNEUMONECTOMY

PATIENT	DATE	ACTIVITY	MV	O ₂ CONS.	CO ₂ PROD.	O ₂ SAT. %	CO ₂ %
Case 1, S. C.* R. pneumonectomy 1/19/50	Preop.	Rest	----	----	----	82.0	----
	1/12/50	Post					
		exercise	----	----	----	----	----
	P. O.	Rest	5.72	.184	.161	94.2	48.6
	9/15/50	Post					
		exercise	16.1	.664	.492	91.2	44.7
Case 2, R. K. L. pneumonectomy 7/18/50	Preop.	Rest	7.3	.242	.262	95.0	50.0
	7/3/50	Post					
		exercise	14.5	.850	.408	94.0	50.5
	P. O.	Rest	5.5	.212	.201	93.6	50.3
	3/20/51	Post					
		exercise	14.8	.783	.557	90.4	49.6
Case 3, R. R. L. pneumonectomy 1/19/51	Preop.	Rest	6.02	.216	.232	92.5	54.3
	1/16/51	Post					
		exercise	12.13	.783	.510	91.2	51.7
	P. O.	Rest	5.53	.178	.175	92.92	47.77
	11/14/52	Post					
		exercise	18.0	.674	.529	92.85	46.24

*This patient was too dyspneic to complete the exercise test.

cent of the total oxygen uptake, as determined by bronchspirometry. In the other two patients the preoperative and postoperative response to exercise was only slightly altered by operation.

In summary the three patients with pneumonectomy and limited contralateral bronchiectasis have obtained symptomatic improvement without developing or increasing already existent dyspnea. A slight to moderate degree of respiratory insufficiency was objectively determined in the group.

GROUP 2. PATIENTS WITH BILATERAL PULMONARY RESECTIONS

Material.—At the time of the second operation the ages of the four men and six women patients ranged from 12 to 47 years, the average age being 26.7 years. Six patients had chronic sinusitis and four had exogenous (nonbacterial) allergic asthma. One patient had situs inversus. The number of segments removed ranged from 7 to 13, the average being 10.1. The interval between the first and second operations ranged from five to forty-six months, and the follow-up clinically was from three months to fourteen years after the second resection.

Results.—Of the ten patients operated upon, eight were improved and two died in the late postoperative period. The first patient who died had a family history of tuberculosis and had had a cough since the age of 5 years. At the age of 7 years he spent eight months in a sanatorium. No tuberculosis was found. At the age of 11 years bronchography revealed bilateral bronchiectasis. When he was 15 one of four cultures was positive. A second positive sputum was never obtained. Roentgenograms taken twice yearly were repeatedly interpreted as negative for pulmonary tuberculosis. When he was 25 years old all the left basal and lingular segments were resected, and the following year a right middle and right lower lobectomy was performed. Initial improvement was striking and the patient exhibited little if any dyspnea. Clinical evidence of active tuberculosis developed seven months later; death occurred fifteen months after the second operation. Autopsy revealed bilateral cavernous tuberculosis, chronic pleuritis, bilateral emphysema, and moderate right ventricular hypertrophy.

The threat of active tuberculosis following lung resection for nontuberculous disease has recently been emphasized by Rothstein and Gerson¹⁵ and earlier by Lambert,¹⁶ who reported a 12.8 per cent incidence of tuberculosis in seventy-eight patients surviving lung resection for nontuberculous bronchiectasis.

If, as seems likely, overdistention of remaining lung tissue is one of the factors responsible for the development of active tuberculosis or activation of latent tuberculosis following pulmonary resection, then great caution is particularly indicated before bilateral resections are performed. In our patient the solitary positive sputum at the age of 15 years and the discovery by the pathologist of caseating tubercles in the left lower lobe after the first resection were clues which might well have contraindicated the resection on each occasion.

The second patient (Case 11, W. R.) died of respiratory insufficiency thirty-four months after the bilateral resections were completed. This patient was dyspneic prior to operation and produced 500 c.c. of thick secretions. Follow-

ing a left lower lobectomy and lingulectomy, a bronchopleural fistula developed which healed spontaneously in five weeks. The patient gained seventeen pounds, subjective dyspnea was essentially unchanged, and the cough was only half as productive. A conservative regimen, including antibiotics, was employed during the next year but secretions were not further reduced. A right lower lobectomy was then performed. The immediate postoperative course was uneventful. He later became increasingly dyspneic with clubbing of the fingers, distended neck veins, and cyanosis. Profuse secretions necessitated frequent bronchoscopies but progressive ventilatory insufficiency and death occurred. Unfortunately facilities for functional evaluation of this patient were not available prior to the operations performed. He was examined in the laboratory for the first time seven months after the second resection.

The studies indicated marked ventilatory insufficiency, poor intrapulmonary mixing of gases and hypoxemia, both at rest and to a marked extent following exercise. This patient had residual lesions in the left upper anterior segment, the right upper posterior segment, and in the right middle lobe. On the preoperative bronchograms, these areas were only minimally involved but the left upper anterior segment became much worse after the first operation. Because of the profuse secretions, we believe that the residual lesions were contributory to death in the patient who was already dyspneic prior to the first operation. Failure to preserve the apical segment of the right lower lobe for fear of the development of pleural complications and bronchiectasis may also have represented a lost opportunity to conserve function.

Of the eight patients who survived bilateral resections, three are greatly improved, four are moderately improved, and one is slightly improved clinically. The symptoms most consistently ameliorated by the bilateral resections were the productive cough and periodic attacks of pneumonia and sinusitis. The average amount of daily sputum prior to the first operation was 120 c.c.; prior to the second operation it was 48 c.c. and following the second operation it was reduced to 29 c.c. (Table IV).

TABLE IV. SYMPTOMS FOLLOWING BILATERAL RESECTIONS

	PRODUCTIVE COUGH			DYSPNEA		
	PREOP. 1	PREOP. 2	P. O. 2	PREOP. 1	PREOP. 2	P. O. 2
Case 4, R. S.	240 c.c.	30 c.c.	8 c.c.	0	0	1+
Case 5, S. C.	240 c.c.	60 c.c.	4 c.c.	0	0	0
Case 6, L. L.	60 c.c.	12 c.c.	8 c.c.	0	0	0
Case 7, P. S.	60 c.c.	8 c.c.	4 c.c.	2+	1+	2+
Case 8, B. C.	60 c.c.	30 c.c.	4 c.c.	0	0	2+
Case 9, G. H.	60 c.c.	30 c.c.	4 c.c.	0	0	1+
Case 10, S. W.	20 c.c.	10 c.c.	0 c.c.	0	0	1+
Case 11, W. R.	500 c.c.	240 c.c.	240 c.c.	2+	2+	4+
Case 12, D. H.	240 c.c.	16 c.c.	4 c.c.	0	0	0
Case 13, V. B.	60 c.c.	30 c.c.	16 c.c.	1+	1+	2+

Subjective dyspnea was present in three patients prior to the first operation and was not increased by the first resection. Following the second resection, however, dyspnea increased in these three patients and developed for the first time in four of the remaining seven patients. These complaints of subjective dyspnea were matched by the objective physiologic determinations.

TABLE V

VENTILATORY STUDIES PRE- AND POSTOPERATIVE BILATERAL RESECTIONS											EXERCISE RESPONSE PRE- AND POSTOPERATIVE BILATERAL RESECTIONS						
PATIENT DATE OF OPERATIONS	DATE OF STUDIES	M.R.C.		VC	IC	ER	RA	FRA	RA × 100 TC	ALV. N ₂	DATE OF STUDY	ACTIVITY	MV	O ₂ CONS.	CO ₂ PROD.	O ₂ SAT. %	CO ₂ V %
		PRE- DICTED	POST- ACTUAL														
Case 5, J. C. L.L. Lobectomy and lingulectomy 10/3/46	7/13/50	64	3467	2329	1459	870	1138	1908	33	2.5	7/19/50	Rest Post	5.03	127	107	95.0	47.8
R.M. Lobectomy Resection R. Basal segments 8/17/50	9/13/50	49	2790	1534	991	643	1256	1899	45	1.46	9/13/50	Rest Post	5.6	706	503	91.5	46.5
		84										exercise	14.6	181	165	95.0	45.9
												exercise	12.8	606	411	92.5	45.6
Case 6, L. L. L.L. Lobectomy and partial linguec- tomy 5/13/50	5/1/50	38	3350	1375	1161	414	1775	2189	52	1.37	5/1/50						
	6/14/51	65	2657	1949	1327	622	709	1330	26	1.07	6/14/51	Rest. Post	9.6	287	261	93.5	47.2
												exercise	18.8	707	494	93.7	46.9
Resection R. M.L. Post. and lateral segments 7/3/51	11/19/52	77	3379	2010	1202	808	1369	2177	40	1.12	12/2/52	Rest Post	5.59	169	136	92.0	40.7
		79										exercise	11.6	991	742	92.0	39.8
Case 7, P. S.	1/29/51	89	5207	3483	2156	1327	1724	3051	33	2.76	1/29/50	Rest Post	5.37	211	150	96.2	47.0
L.L. lobectomy and lingulectomy 1/31/51	5/24/51	86	4362	2280	1591	686	2082	2768	47	2.82	5/24/51	Rest Post	5.21	830	580	95.2	46.0
Resection R. Basal segments 6/25/51	11/15/52	77	5093	2280	1638	642	2813	3155	55	2.37	11/15/52	Rest Post	5.73	733	600	92.0	46.7
		94										exercise	14.9	141	1082	87.3	43.1
Case 8, B. C.	12/11/50	57	4266	2612	1409	1202	1655	2837	38	4.16	12/11/50	Rest Post	4.6	203	150	93.2	45.6
R.M. and R.L. lobectomies 1/5/51	6/5/51	75	3950	2040	1223	817	1542	2650	41	2.0	6/5/51	Rest Post	9.4	640	342	92.1	51.7
												exercise	4.62	163	121	93.2	50.5
L.L. lobectomy and lingulectomy 8/11/52	11/13/52	54	4587	1762	995	767	2825	3592	61	2.1	11/13/52	Rest Post	3.99	118	362	88.8	50.0
Repair B P Fistula 8/19/52		100										exercise	10.8	459	283	80.57	40.0
												exercise	10.8	459	283	76.9	40.0

PATIENT DATE OF OPERATIONS	DATE OF STUDIES	M.B.C.	TC	VG	IG	ER	RA	FRA	RA X 100		ALV.N ₂	DATE OF STUDIES	ACTIVITY	MV	O ₂ CONS.	CO ₂ PROD.	ARTERIAL BLOOD	
									TC	48°							O ₂ SAT. %	CO ₂ V %
Case 9, G. H. R. poudrage 9/7/38	9/30/50	51.0	2627	1368	788	580	1259	1839			2.16	9/30/50	Rest Post exercise	5.31	.172	.183	93.1	63.8
R.L. lobectomy 2/24/39																		
L. poudrage 8/7/39																		
L.L. lobectomy 11/1/39																		
Case 10, S. W. R.L. lobectomy 10/10/46	12/30/52	61.7	3404	2180			1224			36	1.05	12/30/52	Rest Post exercise	4.18	.121		95.3	
L.M. lobectomy, re- section of median basal segment of L.L. lobe																		
Case 11, W. R. L.L. lobectomy and lingulectomy 11/9/48	6/23/50	54.0	5455	2859	1740	1119	2596	3715		48	9.4	6/23/50	Rest Post exercise	4.6	.153	.139	89	48.7
R.L. lobectomy 11/9/49	4/29/52	32.0	----	2217	1306	912	----	----		----	----	4/29/52*	Rest Post exercise	18.1	.757	.611	60	46.3
Case 12, D. H. L.L. lobectomy and lingulectomy 11/11/48	6/28/50	48.0	2658	1429	808	621	1239	1860		43	2.6	6/28/50	Rest Post exercise	4.4	.149	.114	94	47.4
R.M. and R.L. lobectomy 12/6/49	12/10/52	55.0	4941	1803	1099	704	3138	3842		63	2.2	12/10/52	Rest Post exercise	10.5	.556	.361	92.5	47.6
Case 13, V. B. R.M. lobectomy 11/5/48																		
Resection of inferior lingula and L. basal segments 8/23/50	10/11/50	56.0	2792	1347	829	518	1445	1963		51	1.78	10/11/50	Rest Post exercise	5.07	.117	.97	93	48.3
	12/ 9/52	59.0	4611	1534	933	601	3080	3081		64	4.08	12/ 9/52	Rest Post exercise	4.0	.298	.232	92	47.6
																	91.4	40.4
																	77.1	40.5

*This patient was too dyspneic to start the exercise test.

The results of the physiologic studies on nine patients are given in Tables V and VI and in general were as follows:

1. The maximum breathing capacity was reduced in eight patients to from 25 per cent to 83 per cent of the predicted normal values.
2. The vital capacity was reduced in eight patients to from 40 per cent to 95 per cent of the predicted normal values.
3. The youngest patient (Case 6, L. L.), a high school athlete, was the only patient with a normal maximum breathing capacity and vital capacity.
4. The residual air-total capacity ratio was elevated in all patients. The range was 36 per cent to 64 per cent, the average being 50 per cent, indicating considerable overdistention of the remaining lung parenchyma.
5. The alveolar nitrogen after seven minutes of oxygen breathing was significantly elevated in two patients, indicating impairment of intrapulmonary mixing of gases.
6. Hyperventilation was present at rest in eight patients and following exercise in six patients.
7. Hypoxemia was present at rest in seven patients and after exercise in nine patients, seven of whom had arterial oxygen saturations below 90 per cent.
8. One patient had excessive accumulation of arterial carbon dioxide.

An opportunity to evaluate physiologic changes both before and after each of the bilateral resections was presented by the patients in Cases 6, 7, and 8.

In Case 6, L. L., the patient had a subnormal M.B.C. initially. A slight fall occurred shortly after the first resection, with rapid increase thereafter to normal. The second operation did not noticeably interfere with this increase. The RA-TC ratio decreased considerably after the first operation due presumably to the removal of localized emphysematous lung parenchyma. This was verified histologically. After the second resection the RA-TC ratio increased to 40 per cent indicating slight generalized overdistention. Blood gas studies were not obtained before the first operation, but the changes preceding and following the second resection were inconsequential. Essentially the physiologic adjustment has been good following each operation. The present favorable status of this patient is believed to be due to the following: 1. There are apparently no residual or new lesions. 2. There were no complications with either operation. 3. Nine segments remain. 4. The asthmatic component is mild. 5. Youth. The age of maximum functional capacity is still to be attained.

In Case 7, P. S., the maximum breathing capacity was decreased only slightly following each operation, but the RA-TC increased considerably, more so after the first operation. An appreciable gain in total residual air with little change in vital capacity followed the second operation, resulting in an increase in total lung capacity and a final RA-TC ratio of 55. A significant drop in arterial saturation followed the second operation. The increase in respiratory insufficiency occurring mainly after the second operation is believed to be due to progressive emphysema of the lung due to spatial adjustments in a patient with moderately severe allergic asthma. There are ten segments remaining and no new or residual lesions.

The ventilatory and blood gas changes following the first operation were mild in Case 8, B. C. The present physiologically poor state developed following the second resection and is believed to be due to: 1. Complications after the second resection (bronchopleural fistula and pleuritis, a second thoracotomy to close the fistula, and a temporary phrenemphraxis). 2. Only five segments remain. 3. The patient has allergic asthma. 4. There are no residual or new lesions. 5. The studies were performed three months following the second resection.

It is anticipated that improvement in bellows action will occur with return of diaphragmatic action. Whether or not this will be offset by a further increase in the RA-TC ratio remains to be seen.

In summary, of the patients studied physiologically* with bilateral resections, one patient has died of respiratory insufficiency and eight patients have obtained varying degrees of clinical improvement, exclusive of dyspnea which is newly developed or increased in six of these nine patients. All patients have some evidence of respiratory insufficiency, primarily ventilatory in nature, which is marked in five patients.

ROENTGENOGRAPHIC RESULTS

Group 1.—Postoperative bronchograms were not made in the patients who had a pneumonectomy. These patients have had no symptoms or signs of progression of the residual bronchiectasis. Standard roentgenograms show no indirect evidence of increasing lesions such as honeycombing, atelectasis, peribronchial pneumonitis, and fibrosis. A moderate ipsilateral mediastinal shift was present in each patient. This roentgen finding correlated with the mild overdistention of the lung detected by residual air determinations. Postpneumonectomy thoracoplasties were not done in these patients.

Group 2.—Of the ten patients who have had bilateral resections, four have had recent postoperative bronchograms. The four patients all became severely dyspneic and cyanotic during the examination, so much so that we discontinued bronchography on the remaining patients for fear of a fatality. Two patients were able to tolerate bronchographic fill of only one side because of severe hypoxia. These responses constitute additional evidence of a very low pulmonary reserve since it has been shown that only small reductions in vital capacity and inconsequential impairment in alveolocapillary gas exchange occur after bronchography unless an abnormally high gradient already exists.

Three of our patients developed new lesions or showed progression of pre-existing bronchiectasis after operation. This phenomenon has been attributed by Ettinger and her associates¹⁷ to such postoperative complications as pleurisy, atelectasis, and, less commonly, to bronchial rearrangement.

In Case 5, J. C., previously existing bronchiectasis in the lingula became much worse and new lesions appeared in the left upper anterior segment following uncomplicated resection on the left side. This presumably was due to spatial adjustment (Figs. 1 and 2).

*Case 4, R. S. The patient died of pulmonary tuberculosis and was not studied physiologically.



Fig. 1.

Fig. 2.

Fig. 1 (Case 5, J. C.).—Preoperative bronchogram. Bronchiectasis is present in the right middle and lower lobes, the left lower lobe, and lingula. The upper anterior segmental bronchus is incompletely filled.

Fig. 2 (Case 5, J. C.).—A left lower lobectomy and subsegmental lingulectomy has been performed. The bronchiectasis in the lingula and left upper anterior segment has increased markedly.



Fig. 3.

Fig. 4.

Fig. 3 (Case 11, W. R.).—Preoperative bronchogram. There is bronchiectasis in the right middle and right lower lobes, left lower lobe, and lingula. The left upper anterior segment, which is incompletely visualized, appears to contain minimal bronchiectasis.

Fig. 4 (Case 11, W. R.).—After left lower lobectomy and lingulectomy, the anterior segment is markedly bronchiectatic.



Fig 5 (Case 11, W. R.).—A roentgenogram taken five months before death from respiratory insufficiency. The right middle lobe is collapsed. Areas strongly suggestive of bronchiectasis and pulmonary fibrosis are scattered throughout both lung fields.



Fig 6.

Fig 7.

Fig 6 (Case 12, D. H.)—Preoperative bronchogram. There is minimal bronchiectasis visible in the right upper anterior segment, as well as obvious lesions in the right middle and right lower lobes.

Fig 7 (Case 12, D. H.)—The anterior segment has become dependent and markedly bronchiectatic following right middle and right lower lobectomy.

In Case 11, W. R., bronchiectasis in the left upper anterior segment increased greatly after left upper lobectomy and lingulectomy which were complicated by a bronchopleural fistula (Figs. 3 and 4). We believe the natural progression of the disease, as well as pleural complications and bronchial rearrangement were responsible. Prior to death widespread areas of honeycombing and pulmonary fibrosis (Fig. 5) were found in this patient whose symptoms had begun only five years earlier following an attack of pneumonia.

In Case 12, D. H., right upper anterior bronchiectasis increased following right middle and lower lobe lobectomies, complicated by delayed expansion (Figs. 6 and 7).

CARDIAC CATHETERIZATION

The mean pulmonary artery pressure at rest was slightly elevated in one of the three patients, Case 11, W. R. This patient also had some clinical evidence of right heart failure prior to death, which was primarily due to respiratory insufficiency. Since it has been shown that hypoxia,¹⁸ exercise,¹⁹ and extensive reductions in the pulmonary vascular bed can,²⁰ under certain circumstances, cause appreciable increases in pulmonary artery pressure, it is interesting to speculate to what extent these factors influenced the mild degree of pulmonary hypertension in this patient.

The pulmonary artery pressures postoperatively were within normal limits in the two patients who have only five remaining bronchopulmonary segments:

	P.A. PRESSURE MM. HG	MONTHS AFTER SECOND RESECTION
Case 8, B. C.	30-25/10	3
Case 11, W. R.	19 mean	17
Case 12, D. H.	12 mean	18

DISCUSSION

The results obtained in those of our patients who had bilateral resections are generally in agreement with those reported by Taylor and his co-workers.⁵ The conditioning influences prevailing in each series are broadly comparable. The respiratory insufficiency which they found was somewhat less severe than in our patients. They found an elevated residual air fraction in all ten patients and hypoxemia in seven patients. Of the patients studied by Overholt²¹ only four of eight patients had elevations in the residual air and one of five patients had hypoxemia at rest. Blood gas responses to exercise in this series were not reported.

In our experience the general improvement which often follows extensive lung resections for bronchiectasis is marred by subjective and objective evidence of respiratory insufficiency. If resection can be undertaken with little fear of the development of serious respiratory insufficiency, the choice of action is clear and the risk of operations is well taken. When certain physiologically unfavorable premonitory signs are present which augur for a poor prognosis we must ask ourselves how we can improve our selection of patients for operation and how we can avoid increasing the disability if operation is performed. Scannell²² has recently stated that the antibiotics not only increase the safety of the operation but also the safety of having the disease. Conservative treat-

ment may be more frequently indicated instead of operation, or it may be indicated following the first resection even when the lesions are equally distributed bilaterally.

The respiratory insufficiency found after operation has been attributed mainly to residual lesions by some and to postoperative pleural complications by others. We believe that respiratory insufficiency following extensive resections is due to many different factors such as the age of the patient, the presence of pre-existing extrinsic allergic asthma and emphysema, the number of residual lesions, development of new lesions, the paucity of remaining segments, and surgical complications such as bronchopleural fistula with pleuritis, atelectasis, pneumothorax, pleural effusion, and phrenemphraxis. In any one patient, multiple factors usually prevail as is evident in our series (Table VII).

The two most constant factors in those patients who responded poorly were the postoperative pleural and pulmonary complications and the presence of residual lesions. However, residual lesions were present in fifty-five of Rosemond's patients,²⁵ and 25 per cent of these had no cough or symptoms of any kind. One of our patients, Case 5, J. C., has severe residual bronchiectasis in three segments. Although the patient's maximum breathing capacity is considerably diminished, she has a very good clinical result and an excellent physiologic response to the exercise test. Radiographically demonstrable bronchiectasis does not necessarily insure either symptoms or physiologic disability. Our three oldest patients had the poorest functional results in the bilaterally resected group. The two youngest patients had the best results. It is apparent that each patient upon whom extensive resections for bronchiectasis are contemplated must be individually evaluated at various stages of surgical treatment. For example, the preoperative study of the oldest and one of the most dyspneic patients (Case 1, S. C.) indicated that the removal of the well-perfused, but poorly ventilated, diseased lung would improve rather than impair the pulmonary reserve.

When respiratory insufficiency appears imminent the question of what influence the operation will have on the physiologic status must be considered. Will the operation remove one or more of the conditions contributing to the respiratory insufficiency? Among the conditions which will be minimized or eliminated by resection are the following: (1) the toxic factor of the infection, (2) the mechanical factor of secretions of bronchiectatic origin, (3) the perfused atelectatic or locally emphysematous lung acting as a pulmonary systemic shunt, and (4) allergic (endogenous) asthma.

Conditions which are likely to persist as functional handicaps following resection include the following:

(1) Chronic pleuritis, (2) chest wall deformities, (3) generalized emphysema and pulmonary fibrosis, and (4) allergic (exogenous) asthma.

Perhaps when approached from this point of view, together with careful preoperative clinical and functional evaluation and an appreciation of the incidence of physiologically disabling postoperative complications, a lower incidence of significant respiratory insufficiency may be anticipated. Additional information from other series is needed.

TABLE VII. PHYSIOLOGIC STATUS AND INFLUENCING FACTORS. BILATERAL IN PULMONARY RESECTIONS

CASE NO. AND INITIALS	AGE	M.B.C. % N	RA $\times$ 100 TC	ARTERIAL O ₂ SAT. REST POST- EXERCISE	MONTHS AFTER SECOND OP.	REMAINING SEGMENTS	RESIDUAL OR NEWLY INVOLVED SEGMENTS	COMPLICATIONS	COMMENTS
5, J. C.	25	58	45	95/92.5	1	6 $\frac{3}{4}$	3	1. Temporary atelectasis R.U. lobe	0
6, L. L.	14	100	40	92/92	17	8	0		Asthma, mild
7, P. S.	28	81	55	87.3/87.2	17	8	0	1. Temporary atelectasis L.U. lobe	Asthma, moderate
8, B. C.	21	54	61	80/77	3	5	0	1. B.P. fistula, L. 2. Closure B.P. fistula, L. 3. Phrenic-phraxis	Asthma, moderate
9, G. H.	32	44	48	93.1/79	132	9	2	1. Bilateral B.P. fistula. 2. Em-pyema. 3. Chemical pleuritis	0
10, S. W.	16	62	36	95.3/93.4	24	10	0	1. Temporary atelectasis R.U. lobe	Asthma, well- controlled
11, W. R.*	39	43	48	89/60	9	7	4	1. B.P. fistula, L. healed in 5 wk.	0
12, D. H.	21	56	63	90/83	36	5	1	1. B.P. fistula, L. healed in 6 wk.	0
13, V. B.	51	83	64	91.4/77	28	11	0	1. Pleural effusion, R. tempo-rary. 2. Atelectasis, apex L.L. lobe	0

*This patient died 5 months following these determinations.

SUMMARY AND CONCLUSIONS

1. The results of surgical treatment in thirteen patients with bilateral bronchiectasis have been reviewed.

2. Three patients with pneumonectomy and localized residual disease have excellent clinical results with little functional disability.

3. Of ten patients with bilateral resections, there were two late deaths. One was due to tuberculosis and one was due to respiratory insufficiency. The other eight patients are generally improved although all have various degrees of respiratory insufficiency as detected by objective methods.

4. Factors responsible for respiratory insufficiency have been discussed.

5. A plea is made for more frequent use of pulmonary function studies as an adjunct to, but not as a substitute for, careful clinical evaluation.

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(For discussion, see page 179.)

DECISIONS IN THORACIC SURGERY AS INFLUENCED BY THE KNOWLEDGE OF PULMONARY PHYSIOLOGY

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THIS paper is concerned with decisions in thoracic surgery as influenced by knowledge of respiratory physiology and represents our current thinking in an admittedly changing field. It is not our purpose to present detailed statistical data, nor will any attempt be made to compare the therapeutic effectiveness of the various procedures, except in so far as they relate to pulmonary function.

The choice of surgical therapy in treatment of disease of the respiratory system presupposes that it offers the best method of cure or amelioration. Techniques in surgery and anesthesia have advanced to the point where a patient is seldom encountered with pulmonary reserves so limited that he will not tolerate the removal of a few ribs or a thoracotomy done with proper precautions. If, however, normal lung tissue must be collapsed or resected, a procedure extensive enough to accomplish the desired result might not be tolerated. The current mortality rate of both thoracoplasty and resection, exclusive of pneumonectomy, is so favorable that the criterion of a successful procedure is no longer solely that a patient survive the operation and have the disease arrested or eradicated. Our present goal should include the conservation of as much of the patient's cardiorespiratory abilities as possible while bringing the disease under control. We believe that the preservation of reserves for the unforeseeable cardiorespiratory insults of the future is an important consideration and our choice of a particular method of therapy is based on the premise that the method chosen shall combine the greatest possible chance of cure with the least risk to the individual and the least damage to the cardiorespiratory apparatus. The choice of a particular operation is frequently complicated by the fact that one method may be safer but not as promising regarding cure, and vice versa. Different surgeons with the same evidence may decide on different procedures according to their experience.

Commonly the surgeon's assessment of a patient's ability to withstand a particular operation is based solely on clinical judgment, a method we all use but find difficult to define. These clinical methods involve examination of the roentgenogram, observation of the ease of breathing, the appearance of the chest as to whether it is thin and narrow or thick and barrel-shaped, the speed with which the chest can be emptied, and whether breathing is symmetrical. Usually an attempt is made to determine the effect of exercise on the pulse rate and on the ease and comfort of breathing and to note whether

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cyanosis develops. Breath-holding tests are also commonly used. Many patients have undergone surgery successfully with no more evaluation than can be gathered from such evidence. On the other hand, most of us have experienced unanticipated cardiorespiratory difficulties in patients thus assessed.

In the patient with borderline or limited reserves, it is essential that we know as much as possible about the true preoperative state of the cardiorespiratory apparatus. Such data are useful, not only from the standpoint of determining whether or not he will tolerate a given procedure, but also to enable us to choose the particular procedure that he will tolerate best and that will be most conserving of function.

CASE 1—The case report of this patient, F. H. (Fig 1), bears on the reliability of clinical judgment in choosing patients for thoracic surgical procedures. This 31-year-old patient had active extensive bilateral tuberculosis in 1937. On prolonged bed rest, the left lung cleared but some residue remained. In 1939, on the basis of x-ray evidence, it was thought that the left lung was stable and, although not necessarily normal, was in condition to permit a thoracoplasty on the right. Bronchoscopy demonstrated so little movement of exudate in the stenosed right main bronchus that the right lung was believed to be non-functioning. The patient complained of slight dyspnea but on the basis of clinical evidence the patient's condition was considered suitable for a right-sided thoracoplasty.

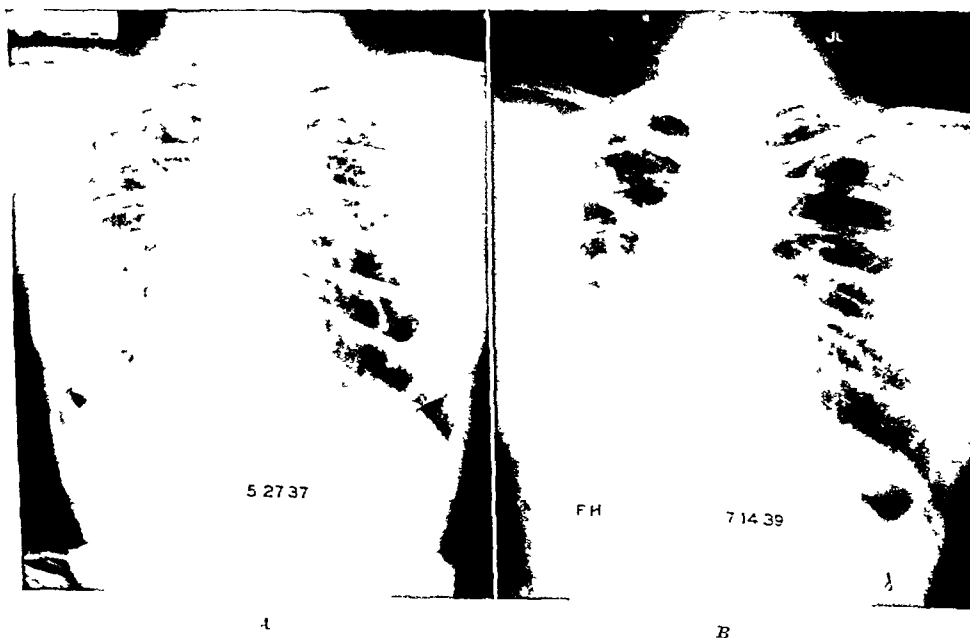


Fig 1 (Case 1)—F. H. was a 31-year-old woman. A. May 27, 1937, extensive bilateral involvement. B. July 14, 1939, prethoracoplasty, marked clearing of shadows in both lungs, residual cavity, right extensive bronchial disease with obstruction right main bronchus.

An eleven-rib thoracoplasty was carried out during a period of two and one half months, the last stage removed the seventh through the eleventh ribs, but only short segments were taken of the lower three ribs. The first two stages were tolerated sufficiently well to encourage the carrying out of the third stage. Following the last operation, how

ever, the dyspnea became very extreme. Distress was so great that the patient could not get out of bed. During the ensuing months she slowly improved, and finally was able to carry out self care. It was noted that during the premenstrual period, breathlessness was so severe that she was unable to tolerate even this slight amount of exertion. One year after the thoracoplasty, the first physiologic studies were made. At that time, the maximum breathing capacity was measured to be 20 L. in the intermenstrual period but fell to 10 L. in the immediate premenstrual period. This patient is still living, sputum is negative, and she is able to do a very modest amount of housework. Slight exertion is accompanied by severe dyspnea. Current physiologic studies show that the maximum breathing capacity is still 20 L. and that the residual air is increased and constitutes 69 per cent of the total volume.



Fig. 1C.—Dec. 18, 1952, thirteen years postthoracoplasty, right.

It is clear that this patient at the time of the operation must have had severe diffuse obstructive emphysema which was unrecognized prior to the operation. Although she survived, the early postoperative period was one of great distress and danger. If physiologic studies had been done preoperatively, we would have handled this case differently.

Other examples of a surgical crisis stemming from failure of clinical evaluation to recognize adequately the severe degree and nature of preoperative cardiorespiratory impairment could be shown from the experience of ourselves and others. That such events occur relatively infrequently is explainable by several facts. First, the cardiorespiratory abilities needed to sustain life are small when compared to the reserves with which the normal human being is originally endowed. In normal persons the cardiac output can be augmented four or five times its resting level, and respiration can be increased fifteen- to twentyfold for brief periods and maintained at tenfold for moderately long periods. With such enormous reserves at the outset,

large portions of the cardiorespiratory abilities can be lost, and an individual will still possess sufficient powers to survive a thoracic surgical procedure. Second, thoracic surgical skill and preoperative and postoperative care have been so improved that little physiologic reserve is needed to sustain life throughout the operation and the postoperative period. The patient in Case 1 probably had but little greater breathing power before the thoracoplasty than she now has. Nevertheless, she survived the procedure. We have carried out a conventional seven-rib thoracoplasty by doing it in small stages over a non-functioning lung in a severely emphysematous 47-year-old man whose preoperative maximum breathing capacity was 38 L., whose residual capacity was 50 per cent of the total volume, and whose arterial blood revealed carbon dioxide retention and mild hypoxia at rest.

A third factor which reduces the incidence of postoperative cardiorespiratory difficulties is the rejection of the bad risk. Since these rejected patients are not operated upon, there is no way of evaluating the adequacy of the clinical method for assessing their suitability for operation. During the past fourteen years, we have studied a number of patients who, previously, on the basis of clinical evaluation alone, had been rejected for thoracic surgery. One of the encouraging facets of our work has been the demonstration by more objective physiologic methods that some of these rejected patients actually possessed sufficient cardiorespiratory powers to permit a properly chosen thoracic surgical procedure. On a few occasions we have found, by quantitative methods, such severely impaired respiratory reserves that we believed the surgical procedure necessary to effect a cure was a greater hazard to life than the disease itself. Thus far, none of these patients has been subjected to surgery and we are, therefore, not in a position to evaluate the correctness of our opinion in these particular cases.

We do not wish to give the impression that we believe the more objective and quantitative physiologic methods of evaluating cardiorespiratory reserves should in any way exclude the conventional clinical observations. On the contrary, we are definitely of the opinion that the two approaches are complementary.

The various physiologic processes whereby gas exchange between the atmospheric air and the pulmonary capillary blood and whereby blood is delivered to and returned from the tissues can be quantitated at rest and under the stress of exercises by appropriate methods. We have found that although these methods add greatly to our study of the effects of disease and therapeutic procedures upon cardiorespiratory function, not all are essential for an adequate evaluation of the preoperative status of the patient being considered for a thoracic surgical procedure.

Fluoroscopic observation with particular attention to the degree to which the lungs can be filled and emptied, to the speed with which filling and, especially, emptying can be accomplished, to evidences of less complete emptying or filling of one portion of the lungs as compared to the other, to movements of the mediastinum; and to the cardiac silhouette will give a well-trained fluoroscopist a good evaluation of the normality of the respiratory

pump. Impaired mobility of the thoracic parietes, regional or diffuse airway obstruction, and abnormalities of the cardiac silhouette that are of a degree significant in our clinical problems can be recognized though not quantitated except in relative terms by fluoroscopic examination. This procedure by itself permits us to recognize those who have sufficient functional abnormality to warrant further quantitative study. Roentgenograms taken at the extremes of inspiration and expiration are useful to confirm the fluoroscopic study and to afford a more leisurely examination. We believe they should be obtained in all cases. By a "trained-fluoroscopist" we mean a person who has had the opportunity of repeatedly checking his fluoroscopically based opinion against quantitative physiologic measurement. Whenever there is any question as to the abnormality revealed by the fluoroscopic study, and in every case when a decision depends heavily upon accurate knowledge of respiratory capacity, quantitative procedures should be carried out. In essence, we consider the fluoroscope a "screening" tool.

The maximum ability of a person to pump air into and out of his lungs is best estimated quantitatively by measuring the maximum breathing capacity.¹ This procedure can be carried out in one of several ways but all are based upon raising the incentive of the patient high enough to obtain a maximum effort. At times the maximum effort may not be obtained, but from a practical point of view the difference between an absolutely maximal effort and a good effort is of relatively little importance. At times, even though the effort is clearly submaximal, the power of the breathing pump will have been shown to be sufficient to warrant classifying the patient as a good surgical risk. When, however, the breathing reserve is low, every effort should be made to obtain a maximal effort during the measurement of the maximum breathing capacity. This test, properly carried out, measures the integrated action of the thoracic parietes, the ease with which air flows through the tracheobronchial structures, the ease with which the lung itself can be distended and collapsed, and the coordination of the muscles involved in respiration. Impairment of any of these factors will be reflected in a lowering of the maximum breathing capacity.

It is frequently essential that accurate knowledge be obtained of the degree to which each lung and sometimes single lobes participate in respiration and gas exchange. The technique of bronchspirometry² serves this purpose. Although fluoroscopic observation will supply a notion as to how much each lung participates in respiration, and angiograms will give some idea as to circulation via the pulmonary artery, neither has sufficient precision and reliability to depend upon them alone when a critical decision must be made. Moreover, bronchspirometry is the only method that will reliably measure the extent to which each lung participates in oxygen uptake.

The procedures thus far mentioned, together with the customary clinical evidence, will provide sufficient information in most cases upon which to base a decision concerning the operative risk and choice of operation.

When the maximum breathing capacity is moderately or severely reduced, one always suspects the presence of diffuse obstructive emphysema. This

abnormality is the most common cause for respiratory impairment and is the condition most likely to lead to operative and early postoperative crisis. A low maximum breathing capacity is also to be found in pathologic conditions other than diffuse obstructive emphysema. Because of its serious import, it is essential that the surgeon recognize those patients whose low maximum breathing capacity is caused by diffuse obstructive emphysema as contrasted to those whose low maximum breathing capacity is not due to diffuse airway obstruction. Measurement of the residual capacity will aid in this regard because diffuse obstructive emphysema of a significant severity is always associated with an increase of the residual capacity both in absolute terms and also when expressed as a percentage of the total lung volume. Pulmonary volumina measurements must be interpreted with caution. A reduction of total volume may cause a normal residual capacity to appear to be increased when expressed as percentage of total volume. A combination of low maximum breathing capacity and elevated residual capacity expressed in absolute volumes is pathognomonic of diffuse obstructive emphysema.

Study of the arterial blood and alveolar gases is rarely needed in evaluating the patient for thoracic surgery. We have not found arterial hypoxia to be a significant contraindication for surgery. Evidence that carbon dioxide is being retained is of great importance, but it is possible to proceed without blood gas studies on the basis that in all cases of diffuse obstructive emphysema, retention or at least subnormal elimination of carbon dioxide will be present whereas in other pathologic circumstances retention of carbon dioxide is rare.

We have not found that the measuring of the volume of air breathed at rest or during mild exercise is of significant help in deliberations concerning the choice of operation or operability of the patient. Generally a reliable measurement of breathing discloses normal volumes at rest and during exercise in most persons whose disease is amenable to treatment by thoracic surgery. Pleural disease requiring decortication and arterial venous aneurysm of the lung are at times characterized by abnormally large air exchange, especially during exercise. In both of these situations the surgical correction is followed by a drop in the volume of breathing to near-normal or normal levels.

The role of cardiac catheterization studies in the evaluation of patients for surgical treatment of pulmonary disease has not been established. There may be a limited and at times critical need for such study.

We have deliberately omitted any discussion of measurements of the vital capacity because in our experience this procedure has had little value and at times has actually been misleading.

Knowledge of the degree to which the lungs resist distention and collapse—reflected in the M.B.C. (maximum breathing capacity)—is of critical importance in regard to the development of paradoxical chest wall motion. If the thoracic cage has its support removed, as by thoracoplasty or crushing injury to the thorax, a lung of normal resistance will to some extent keep the

chest wall from expanding properly during inspiration. When the lung has been made abnormally resistant to distention by fibrosis, airway obstruction, or envelopment in a pleural membrane, the impediment to chest wall motion is proportionately more severe. In the presence of airway obstruction, the chest wall not only sinks in during inspiration but also balloons out during expiration. The serious and at times fatal consequences of paradoxical chest wall motion are so familiar as to need no further discussion.

Diffuse airway obstruction interferes with proper ventilation of the alveoli and leads not only to hypoxia but, equally important, to carbon dioxide retention. The severe degree of respiratory acidosis that may develop during an open-chest procedure, although by now adequately demonstrated, is inadequately appreciated.³ That this situation would be especially prone to develop, and in fact be difficult to avoid, in the presence of diffuse obstructive emphysema is readily understandable. The fact that severe acute respiratory acidosis is usually survived is no excuse for ignoring its occurrence. It is highly probable that some of the cardiac arrhythmias of the operative period are directly attributable to the acidosis. It is now well recognized that the inhalation of oxygen-enriched mixtures by persons with severe respiratory insufficiency secondary to diffuse obstructive emphysema, though it corrects the hypoxia, may lead to severe carbon dioxide retention and associated stupor, coma, and even death.⁴ That a similar situation can develop during the operative and postoperative period when patients with severe obstructive emphysema undergo surgery was recently demonstrated to us. Recognition of this possibility and the institution of proper measures to avoid or treat the complication may be lifesaving.

A lung that is already operating at a mechanical disadvantage because of increased resistance to deformation may be placed at further disadvantage by being further distended in order to fill a space left by the resection of lung tissue. This problem will be discussed in more detail later. Recognition and quantitative measurement of the severity of respiratory impairment caused by fibrosis and diffuse obstructive emphysema is to us of sufficient importance and assistance in planning and carrying out thoracic operations to warrant the required laboratory procedures.

The most important surgical procedures affecting respiratory function are thoracoplasty, resection, and decortication. The patient with impaired pulmonary function who is undergoing either thoracoplasty or resection is relatively safe while actually on the operating table. Surgical and anesthetic accidents are always a hazard but the surgical team is in its optimum position to intervene. The anesthesiologist, particularly if he has the control afforded by intratracheal anesthesia, should be able to maintain oxygenation and prevent dangerous accumulation of carbon dioxide, except in those patients with diffuse obstructive emphysema. In these, while the anesthetist can force air into the lungs, he usually has no means enabling him to assist expiration. In such patients, carbon dioxide retention with its potentially dangerous sequelae is virtually certain to develop. Judicious haste to keep the duration

of the anesthesia as short as possible is important in these cases. It is possible that intermittent hyperventilation with manual assistance to the expiratory phase might be useful.

A clean airway is desirable at all times but is especially so in those patients with diffuse obstructive emphysema because the already narrowed airways are easily occluded. Good aspiration technique is essential. If the patient is properly prepared before the operation, there is usually a minimum of secretions, especially in the tuberculous patient who has been on long-term chemotherapy. In resection for bronchiectasis, the surgeon is more likely to encounter copious secretion and every effort to control these before and during the operation should be made.

The early postoperative period is one of considerably greater hazard. Airway obstruction and carbon dioxide retention must be avoided regardless of the difficulties this may entail. Whereas the patient with good cardio-respiratory reserves will survive airway obstruction and its sequelae and at a later date appear none the worse, the patient with seriously impaired cardio-respiratory reserves under the same circumstances may not survive. Cough cannot be relied upon in these handicapped patients. To keep the airways clean in the presence of moderate to copious secretion may require aspiration every half hour for several days. Usually this can be accomplished by tracheal suction through an intranasal catheter, but where secretions are profuse or the patient's reserves low we do not hesitate to perform a tracheostomy before the patient leaves the table. A clean airway will do much to prevent postoperative hypoxia and carbon dioxide retention. Control of pain by local anesthesia so that narcosis can be kept to a minimum is also important. Oxygen therapy should be used sparingly for the reasons discussed earlier. If the patient will not or cannot use the respiratory apparatus vigorously, it may be necessary to use a tank respirator with both negative and positive pressure. The use of this apparatus should not be delayed.

Severe paradoxical chest-wall motion is a serious problem which may occur during the postoperative period. The larger the area of poorly supported chest wall and the more resistant the underlying structures are to distention, the more severe the paradoxical motion will be. Prevention is much more effective than treatment of this serious condition. Preoperative realization that the underlying tissues are more resistant to distention and collapse than normal gives ample warning that if a soft chest wall must be created, the area should be kept small. Resection of anterior ribs should be done with great caution because this area has no support after the ribs are removed and also because the first, second, and third ribs support almost the entire anterior chest wall. Better still, another procedure such as extra-periosteal plombage, which maintains a strong chest wall in the presence of the desired lung collapse, might be chosen.

Following pulmonary resection it is important that the mediastinum be kept in as nearly normal a position as possible in order that the lung tissue on the opposite side have unimpaired expansion. The routine use of a drainage tube connected to a water seal and to wall suction at -15 cm. of water pres-

sure for the first forty-eight to seventy-two hours will protect against the development of an unusually high or low pressure on the operated side and consequent marked shifting of the mediastinum. If a large volume of good lung has been left on the side of the resection, the space is promptly obliterated and significant displacement of the mediastinum does not develop. The question of handling a large residual space will be dealt with later.

Sudden alterations of the cardiorespiratory system are less well tolerated than those that develop slowly. During the early postoperative period, this is especially evident. Vigilance and prompt vigorous countermeasures during the first twenty-four to forty-eight postoperative hours will save lives that would otherwise be lost. Preoperative knowledge of the degree and exact nature of cardiorespiratory impairment will assist the surgeon in avoiding postoperative emergencies and will greatly enhance his ability to recognize and cope with them.

The limit of acceptable risk for resection and removal of functionless lung tissue is now remarkable. We have recently carried out preoperative studies on three patients subsequently operated on by Dr. Donald Miller of Burlington, Vt. Their maximum breathing capacities were 30, 20, and 18 L. and their residual capacities constituted 72, 74, and 78 per cent of the total volume. In none of these was there evidence of cardiocirculatory failure. All of these very severe cases of diffuse obstructive emphysema successfully underwent a thoracotomy and resection of blebs and bullae. In one of these cases, Dr. Miller used a respirator in the immediate postoperative period in order to overcome severe carbon dioxide retention. We have never attempted a thoracoplasty on such severe cases.

CASE 2.—Nevertheless, one of us has done an extraperiosteal Lucite plombage creating a defect the equivalent of a six-rib thoracoplasty in one stage on a patient (Fig. 2), whose maximum breathing capacity was only 40 L., whose residual air of 3.62 L. was 62 per cent of the total volume, and whose lung on the side of the plombage was doing 36 per cent of the total oxygen uptake before the operation. This patient with severe diffuse obstructive emphysema withstood the operation without difficulty. It is apparent that patients who have been thoroughly demonstrated to have severe respiratory impairment can undergo properly chosen surgical procedures involving the thorax if the surgeon is adequately forewarned.

Loss of function measured six months to one year following a conventional thoracoplasty is caused by collapse of functioning healthy lung tissue and limitation of motion of the thoracic parietes. Quite commonly no measurable loss of pulmonary function follows the thoracoplasty, especially if the operation is confined to the diseased area and severe scoliosis is prevented. In a series of 50 cases that we studied before and one year after thoracoplasty, we found the maximum breathing capacity to be unchanged, or in some instances slightly increased, in twenty-three patients. The average decrease in the remaining twenty-seven cases was $13\frac{1}{2}$ per cent with extreme of 35 per cent.

In this series, 50 per cent of the patients had six or fewer ribs resected. Forty patients in this series had bronchspirometric studies before and after thoracoplasty. Of these, eleven showed no change or slight improvement of

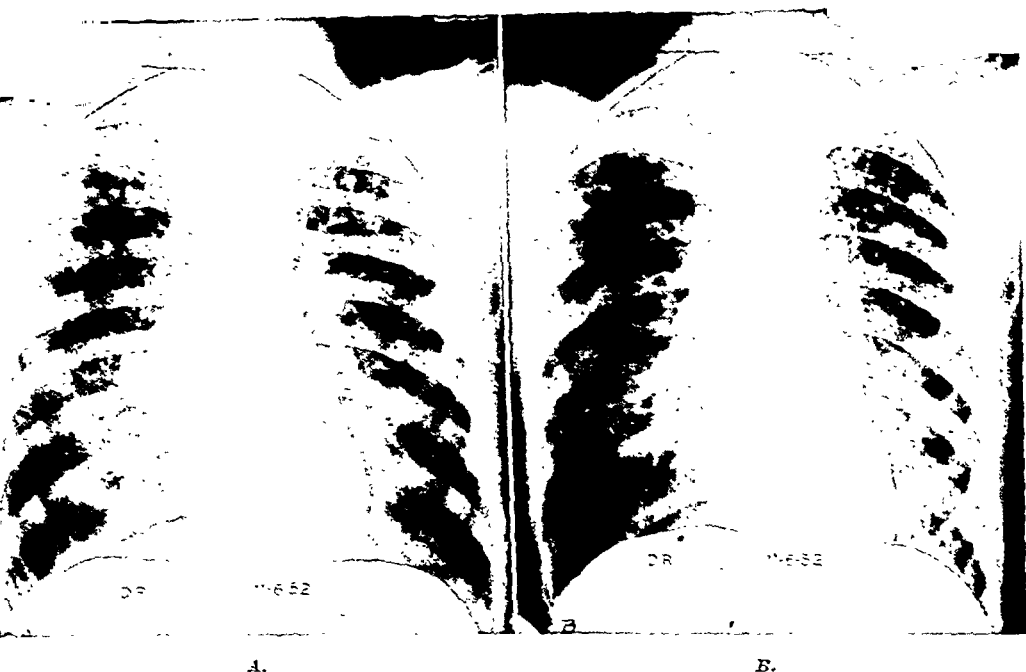


Fig. 2 (Case 2).—D. R. was a 51-year-old man. Duration of disease was twenty-eight years. Dyspnea was present at rest and marked on slight exertion. A. Nov. 6, 1952, full inspiration. B. Nov. 6, 1952, full expiration shows marked impairment of ability to exhale.



Fig. 2C.—March 9, 1953, six days after a five-rib extraperiosteal thoracoplasty with Lucite plombage.

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function on the side of the operation. The mean reduction in the remaining twenty-nine was $22\frac{1}{2}$ per cent with extremes of 4 per cent to 46 per cent. In this series, twenty-one patients had four to six ribs resected with no more than two of the ribs being resected anteriorly. Of these, eight showed no change and the mean reduction of the remainder was 17 per cent, with extremes from 4 per cent to 33 per cent. In nine of this series, a seven- or eight-rib thoracoplasty was done, and in this group all showed a decrease in function postoperatively, the mean being 20 per cent and the extremes 11 per cent to 44 per cent.

The large extent to which the homolateral lung still functions in the presence of a six-rib thoracoplasty is impressive. The reasons for this are several. First, the majority of the motion of the thoracic parietes comes from diaphragmatic and lower chest-wall motion, areas not involved in a six-rib thoracoplasty. Second, already damaged lung undergoes most of the collapse. Third, healthy lung, if under the collapsed area, is displaced downward and being still in the distended state is circulated by blood and can be ventilated by lower thoracic and diaphragmatic motion. Fourth, while it is true that all of our cases showed a reduced vital capacity postthoracoplasty, the maximum breathing capacity is but little influenced, because this maneuver is accomplished with excursions of less than vital capacity stroke, and as the stroke is diminished the rate of breaths per minute can be accelerated.

In this series, the factors which seem to be significant in those who suffered an appreciable loss in function as the result of the thoracoplasty were (1) removal of more than six ribs, (2) collapse of an appreciable amount of good lung tissue, and (3) the development of a significant degree of scoliosis.

In uncomplicated resection, the thoracic parietes are not injured and within a few months after the operation can be moved as well as before. The degree by which cardiorespiratory function is impaired following uncomplicated resection is related solely to the volume of tissue removed. If healthy lung is resected, the chances of diminished function are greater than if only diseased lung is removed. If pleural changes sufficiently severe to limit motion of the parietes ensue, or if the lung fails to expand to fill the space properly, the postoperative impairment is more severe than when these complications are absent. Since the size of the thorax is not appreciably diminished by pulmonary resection, the tissue which remains after the operation becomes more distended in all phases of the respiratory cycle as it expands to fill the space. If a wedge, segment, or lobe that has been markedly contracted prior to resection is removed without complications, one often cannot discover any difference in the cardiorespiratory measurements before and six months to one year after the operation.

CASE 3.—This case demonstrates the paucity of changes following resection of a small amount of lung tissue (Fig. 3, Table I).

If larger volumes of lung are removed, the remaining lung tissue becomes so increased in distention, as it fills the space, that it exerts sufficient centripetal pull to lessen the size of the thorax. The balances of force are so disturbed that the outward movement of the parietes is limited, causing the total capacity and vital capacity to be reduced, and the maximum breathing capacity is likely to be diminished. However, however, capable of reducing itself to its

TABLE I

	M. B. C.			TOTAL CAP.			RESID. CAP.			RC TC × 100	BRONCHOSPIROMETRY % DONE BY SINGLE LUNG					EXERCISE	
	IN L.			IN L.			IN L.				LUNG	M.V.	O ₂	CO ₂	V.C.	ART. BLOOD	
	PRED.	DET.		PRED.	DET.		PRED.	DET.								% HGB.	
Case 3																	
Presection	163	163		6.36	6.93		1.28	2.12		31	Left	49	45	49	50	93	
Postsection	163	162		6.36	6.48		1.28	1.96		30	Left	47	41	47	45	94	
Case 4																	
Prethoracoplasty	162	122		6.71	5.68		1.64	1.90		33	Left	41	26	38	33	94	
Postthoracoplasty	162	118		6.71	5.17		1.64	1.27		30	Left	27	21	24	31	95	
Case 5																	
Predecortication	*	104		5.96	3.73		0.79	0.69		19	Right	39	27	31	21	97	
Postdecortication		145		5.96	5.55		0.79	0.97		18	Right	52	48	50	41	96	
Case 6																	
Presection	171	116		5.62	4.75		1.11	1.60		34	Right	19	6	5	?	89	
Case 7																	
Pre-Monaldi	97	70		3.70	3.31		1.04	1.15		35	Right	48	48	47	46	--	
Case 8																	
Prethoracoplasty	95	47		4.65	2.42		1.32	1.04		43	Left	45	50	49	45	--	
Case 9																	
Prethoracoplasty	137	70		5.68	2.82		1.39	0.97		35	Left	21	20	16	32	--	
Post left thoracoplasty	137	68		--	--		--	--		--	Left	22	20	17	27	--	
Post bilat. thoracoplasty	137	53		5.68	2.25		1.39	1.00		45	--	--	--	--	--	--	
*Too young for thoracoplasty																	

*Too young for prediction formula.

†Residual Capacity × 100.
Total Capacity

We do not possess or know of data which will permit a definitive comparison of the quantitative aspects of the physiologic alterations in thoracoplasty as opposed to resection. It is our opinion that in the absence of complications (including scoliosis) and if comparable volumes of healthy lung tissue are spared, there will be little difference between the end results of the two procedures. There are, of course, many circumstances in which resection will be far more sparing of healthy lung tissue than is thoracoplasty. The reverse rarely, if ever, occurs. Complications, such as the development of moderate to severe scoliosis after thoracoplasty, the development of pleural membranes after resection, or unusual thoracic discomfort after either operation, quite obviously will alter the anticipated functional end result.

In the presence of a totally destroyed lung, some degree of overdistention of the remaining lung and some degree of scoliosis usually exists prior to the operation. In this situation pneumonectomy usually causes less further loss of function than does a total thoracoplasty. Generally speaking, when thoracoplasty and resection are being considered for the same patient, the procedure least likely to embarrass or sacrifice healthy lung tissue has the physiologic advantage. It is our opinion that complications of physiologic significance are more common in pulmonary resection than in thoracoplasty; hence at times the undesirable complications of resection partially offset what preoperatively appeared to be an advantage of saving useful lung tissue by carrying out a resection instead of a thoracoplasty.

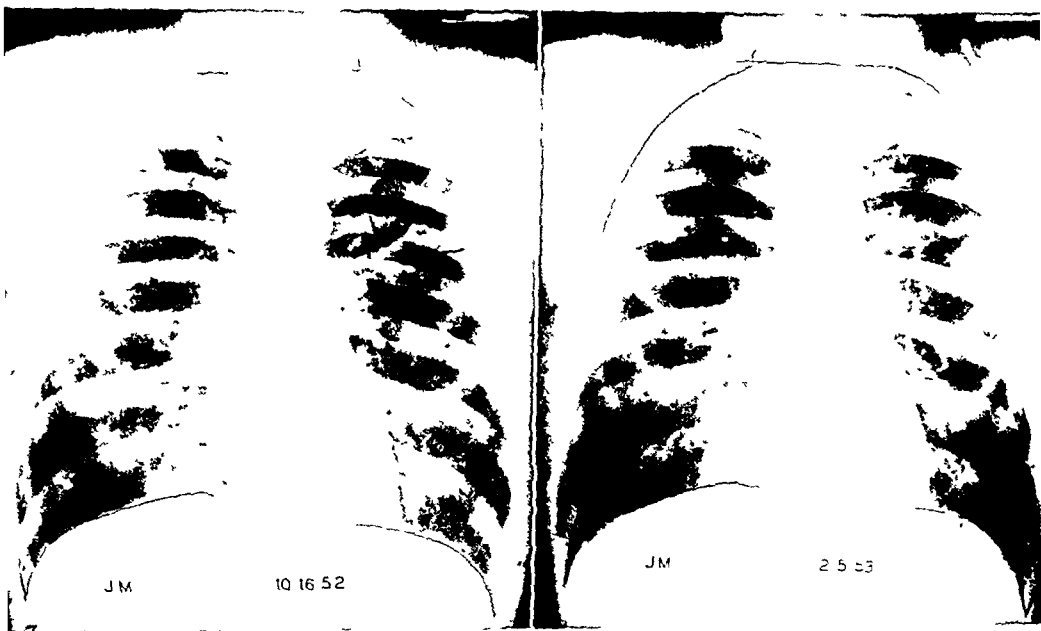
The question of whether or not some sort of space correcting procedure should be carried out in association with pulmonary resection revolves around three factors: (1) the likelihood that a residual space will persist, (2) whether or not the overdistended lung will have less capabilities for cardiorespiratory performance than if not permitted to overdistend, and (3) whether or not residual foci in the overdistended lung will spread or be reactivated and the new disease be less successfully controlled.

The first of these factors depends entirely upon the individual situation and is not strictly a matter involving pulmonary physiology.

The second factor, namely, the effect of overdistention on pulmonary function, has been the subject of considerable investigation. The early studies involved chiefly overdistention following pneumonectomy and suggested that marked overdistention caused a diminution of pulmonary function. Our experience and that of others indicates that, after wedge and segmental resection, there is none or but slight functional change and that the slight overdistention can be ignored. When a shrunken lobe is removed, the remaining lung is overdistended before resection and postoperative studies disclose no further change. If a large amount of healthy lung is removed during lobectomy, a drop in maximum breathing capacity and a slight decrease in ventilation with a more marked decrease of oxygen uptake by the lung remaining on the resected side usually occurs.

CASE 4.—In our experience, as shown in this case a tailoring thoracoplasty has little effect on the maximum breathing capacity, except to decrease it slightly and to diminish

former size during maximum expiration; hence the residual capacity usually shows little or no change in its absolute volume. These comments as to pulmonary volumes relate to the lung tissue as a whole that is present before and after operation. Considering a single lung, for example, the right lung before and after removal of a moderately good left lung, it is obvious that as the remaining right lung enlarges to help fill the space of the removed left lung, the total volume of the right lung will become definitely larger at full inspiration and also will be larger at full expiration than it was prior to resection. This enlargement is referred to as "emphysema" and has been grossly misinterpreted to be synonymous with diffuse obstructive emphysema, whereas the two conditions are strikingly different, especially as to quantitative aspects of functional impairment.



A

B.

Fig 3 (Case 3) —J. M. was a 36-year-old man, onset disease, 1948, increase of disease and symptoms, 1952. Tubercle bacilli never found. Combined antibiotic therapy five months. Wedge resections of left upper and lower lobes by Dr. E. S. Welles, October, 1952, showed both lesions to be solid and caseous. The larger one, 2 cm in diameter, showed Gaffky III but was negative on culture and guinea pig. A, Oct. 16, 1952, solid tuberculous lesions, posterior segment left upper lobe and superior segment left lower lobe. B, Feb. 5, 1953, appearance after wedge resection on Oct. 27, 1952.

If any useful lung tissue is left on the side of the resection, bronchspirometric measurements will show slight to marked reduction in the function of the remnant depending on the volume of useful lung that was removed. Almost without exception the remnant participates more in ventilation than it does in oxygen uptake. This is to be expected since ventilation is chiefly a function of the relatively undisturbed thoracic parietes, while oxygen uptake is a manifestation of blood flow through the lung. Apparently the stretched airways and alveoli function better than does their stretched vascular bed.

The question of whether or not prolonged overdistention will eventuate in true obstructive emphysema cannot be answered at this time. We have observed one patient, with overdistention of both lower lobes resulting from marked contraction of both upper lobes, who in the course of sixteen years has not developed any evidence of true diffuse obstructive emphysema. More time must elapse before this important question can be clarified.

The third factor, namely, that the overdistended lung may have less capabilities to control old and new tuberculosis is also still debatable. Past experience suggested that the overdistended lung was less able to control tuberculous infection and some support for this belief was obtained from the concept that overdistention is the opposite of relaxation, the latter being considered an important factor promoting healing in tuberculous infection. Present evidence, however, indicates that under chemotherapy spreads and reactivation of tuberculosis are less common after resection than was formerly true. At the Twelfth Veterans Administration Army and Navy Conference on Chemotherapy of Tuberculosis,⁶ data were shown indicating no significant difference between two groups of patients, all of whom had received chemotherapy: one group had a thoracoplasty after the lobectomy; the other had no thoracoplasty after lobectomy. A critical evaluation of this data requires more information than was furnished. Nevertheless, it strongly suggests that a tailoring thoracoplasty is of unproved value in protecting the remaining lung against tuberculosis after resection.

The evidence against the necessity of a space-correcting thoracoplasty following resection is mounting. We are doing them less and less frequently, but still prefer to individualize. If freshly healed disease or large nodules are left behind and overdistention of a severe grade is anticipated, we still do a space-correcting thoracoplasty. If experience shows this to be unnecessary, this procedure too will be abandoned.

Up to this point emphasis has been placed upon the use of procedures which are likely to cause further decrease in respiratory function. There are two conditions in which surgery may increase respiratory reserves. These are (a) the lung which is encapsulated in an inelastic peel, and (b) the lung in which large cysts have so displaced and compressed the remainder of the lung that respiration is impaired.

The removal of a thick encapsulating peel is usually not difficult, but we have advised it only when we have believed that the patient would obtain significant benefit by its removal. When fibrin is deposited upon the lung and the thoracic parietes, it becomes organized and is less yielding than the normal pleural membrane. The amount of consequent impairment is dependent upon the degree to which the peel resists stretching and the extent to which the underlying lung has been damaged by intraparenchymal disease and the extent to which healthy lung tissue is collapsed. Mere symphysis of the pleurae causes no measurable alteration of function, but if the lung and thoracic parietes become less freely movable by reason of a relatively unyielding "envelope," there is always a reduction in the degree to which the under-

ventilation with slight further decrease of oxygen uptake on the resected side (Fig. 4, Table I). Our evidence indicates that a five- or even a six-rib tailoring thoracoplasty after lobectomy has no beneficial and but little further harmful effect on pulmonary function.

After pneumonectomy, if the remaining lung is permitted to fill the chest completely, overdistention may be marked though under some circumstances the remaining lung contributes relatively little to filling the space and is consequently but slightly overdistended. Generally, the severe overdistention after pneumonectomy will be associated with a reduction of the maximum breathing capacity. In some this is slight, and in others, moderately severe. A space-correcting thoracoplasty to avoid severe overdistention uniformly causes further slight to moderate reduction of the maximum breathing capacity. Gaensler

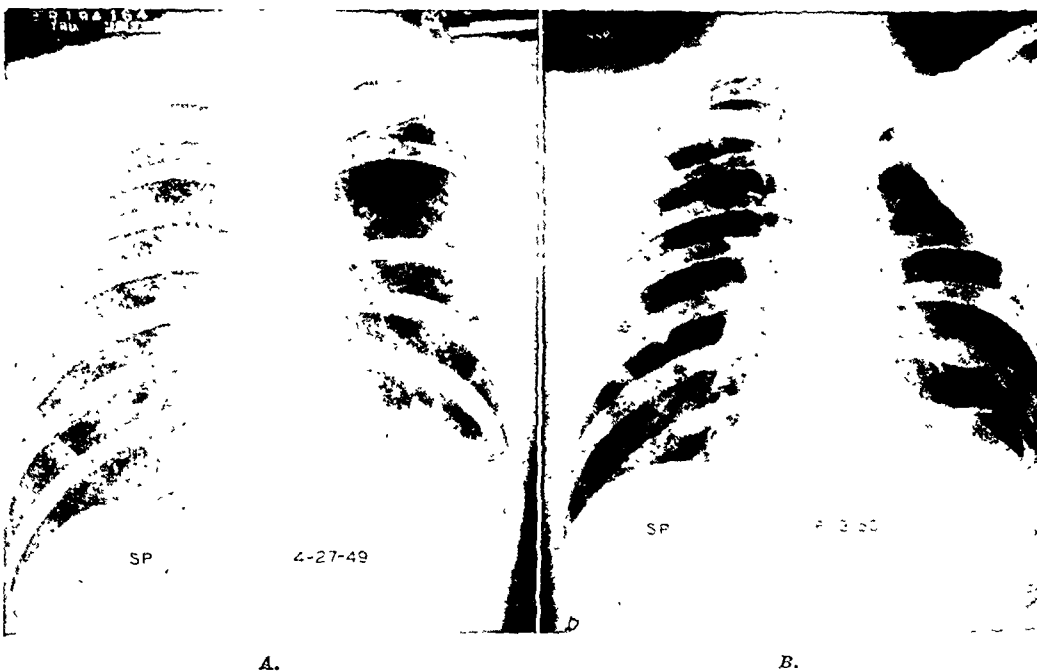


Fig. 4 (Case 4).—S. P. was a man, 36 years old; left upper lobectomy March 4, 1949, tuberculous stenosis left upper lobe bronchus; tailoring thoracoplasty, left, May 14, 1949. A, April 27, 1949, left hemithorax filled by overdistended left lower lobe. B, June 13, 1950, after tailoring thoracoplasty, ribs one to five; rib six resected at time of lobectomy.

and Strieder⁵ have demonstrated that if overdistention is prevented by plompage of air or Ivalon sponge, resection of a nonfunctioning lung causes no loss of maximum breathing capacity. At present, from the standpoint of pulmonary function alone, we do not believe a thoracoplasty is indicated after resection except possibly following pneumonectomy. Until we know that severe displacement of the mediastinum is benign from a cardiocirculatory aspect over a period of years, we prefer to avoid severe displacement. We believe that a plompage is a more physiologic way to prevent the displacement, but prefer to accept the impairment caused by thoracoplasty until shown that plompage can be tolerated for years without infection.

The alternative to decortication would have been an extensive thoracoplasty. This patient now has essentially normal function. Thoracoplasty would have resulted in further loss. Being a young boy with an excellent opposite lung, he probably would have tolerated this procedure but would have been unnecessarily handicapped for the future.

In general, we have found no correlation between the length of time a lung has been collapsed and the degree of success of decortication. The effect of decortication as a means of obliterating an empyema space is beyond the scope of this paper.

In decortication for the restoration of function removal of the parietal, as well as the visceral, peel should be performed. The maximum improvement can be obtained only by removing the peels over the diaphragmatic surface and freeing the costophrenic sinus.

The way in which a preoperative quantitative evaluation of cardiorespiratory function may serve a utilitarian purpose is demonstrated in the following series of patients.

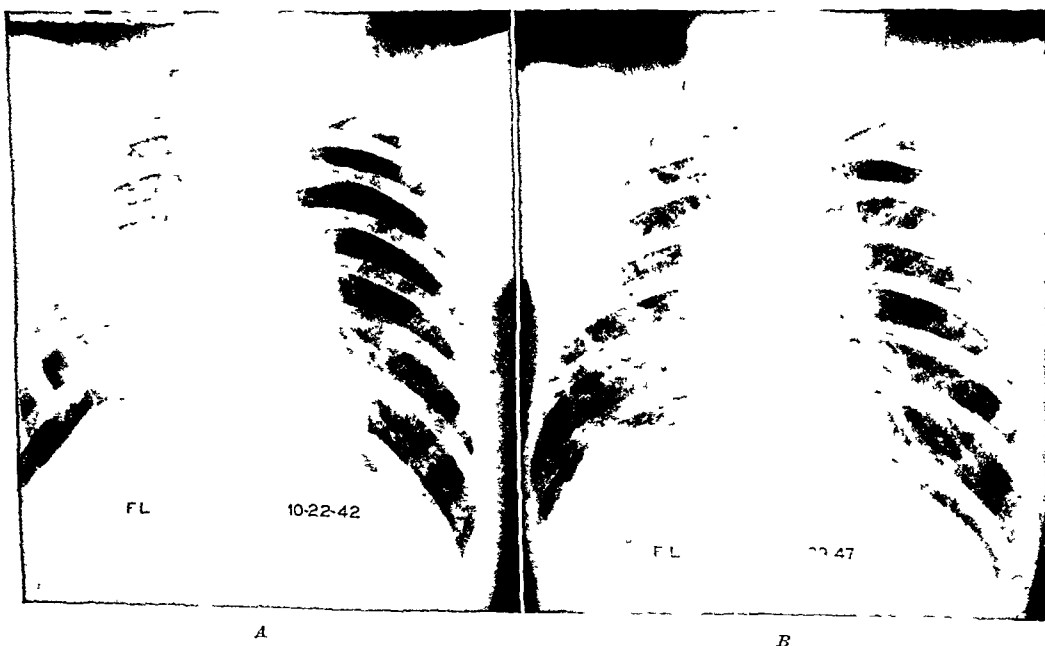


Fig 6 (Case 6)—F. L. was a man 31 years old; extensive tuberculosis, right lung, five years. Disease which developed on left subsequently cleared. A, Oct 22, 1942, disease throughout right lung. B, April 29, 1947, cavities, right lung. Despite appearance of films, physiologic studies revealed right lung to be virtually nonfunctioning.

CASE 6.—F. L. was a 31-year old man, known to have had bilateral tuberculosis since the age of 26 years. The left lung cleared, leaving virtually no visible residue. At the time of our studies, the right lung contained two thin-walled cavities and a few scattered nodules. On the basis of clinical evidence alone, this patient had been selected for pneumothorax on the right side, but a routine precollapse fluoroscopy in our laboratory revealed striking evidences that the right lung could not be emptied to nearly as complete an extent as could the left lung.

lying lung participates in respiration. The effect of this on "total" respiratory function may be slight to marked, dependent upon the function of the opposite lung.

When there is no residual pleural space and loss of function of the incarcerated lung is slight, there would seem to be little reason to decorticate, because decortication itself is rarely so skillfully performed that the end result is a normally functioning hemithorax. Also, there is little to be gained by removing the peel and restoring mobility of the chest if the underlying lung has been so badly damaged that normal gas exchange is impossible. In such instances, even though ventilation may be increased, there may be little or no increase in oxygen absorption.



Fig. 5 (Case 5).—F. S. was a 17-year-old boy; acute onset, pleurisy with effusion, 1950; developed into tuberculous hydropneumothorax. Lung could not be expanded. Decortication Sept. 9, 1950, thick parietal and visceral peels containing tuberculous granulation tissue were removed. A, Aug. 16, 1950, hydropneumothorax, right. B, April 6, 1951, seven months post-decortication. There is still evidence of peel along lower mediastinum and over diaphragm.

We have frequently been unable to predict the effect of a technically successful decortication on pulmonary function. In this regard, it is helpful to study roentgenograms of the lungs before pleural trauma occurred. If these roentgenograms suggest that a large volume of healthy lung tissue has subsequently become encased, a decortication would seem advisable. The maximum chance of benefit seems to be in those cases in which a lung with disease of slight extent has been encased in a peel while under a high degree of collapse.

CASE 5.—This case illustrates the effectiveness of decortication. F. S., a 17-year-old boy, had an early tuberculous empyema. The lung could not be expanded. Table I gives the data before and after decortication (Fig. 5).

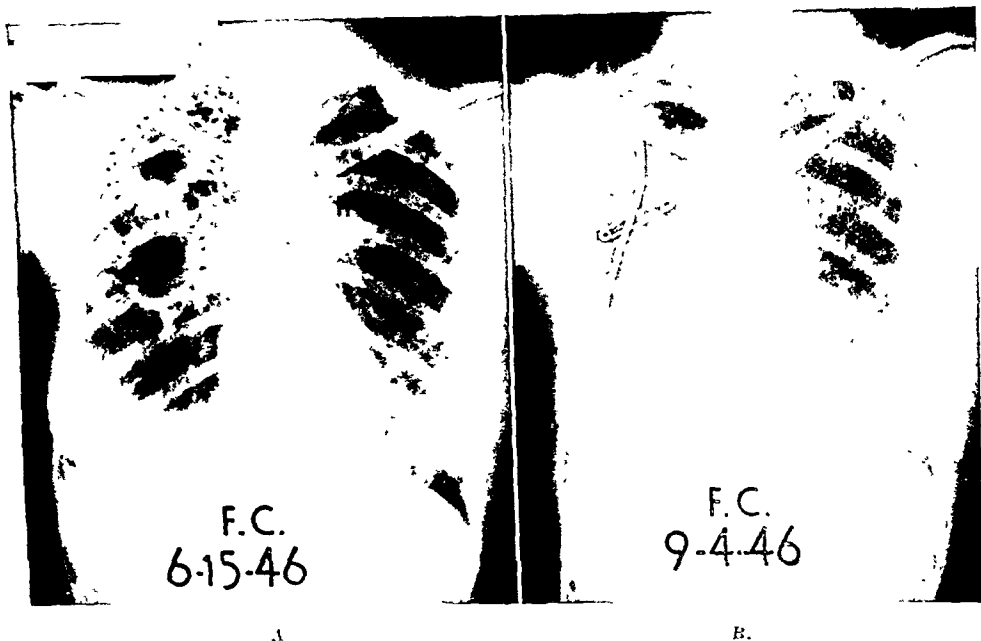


Fig. 7 (Case 7).—F. C. was a 21-year-old woman; onset age 16 with extensive disease, left. Treated by bed rest and temporary phrenic, left, with resolution of disease. Readmitted five years later with two large cavities, right. Both became larger under pneumothorax which was abandoned. Physiologic studies prior to pneumonectomy. A, June, 1946, right lung despite two large cavities was accounting for 48 per cent of oxygen absorption. Lateral films revealed both cavities to be posterior. Although left lung now relatively clear, its function is impaired. B, Sept. 4, 1946, Monaldi catheter in place in upper cavity, anterior approach. Cavity not visible. Lower cavity not visible after posterior resection of ribs five to eight, preliminary to posterior Monaldi drainage; catheter never introduced because of cavity closure.

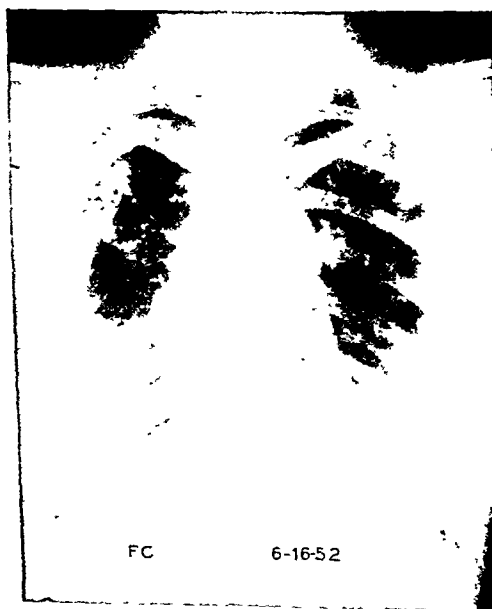


Fig. 7C.—June 15, 1952, appearance six years later. Patient at home, sputum negative.

From this finding we suspected extensive bronchial disease, but bronchoscopic examination showed no abnormality in either bronchus, other than some reddening around the right upper lobe bronchus. This area bled easily. The paucity of bronchoscopic findings, together with the fact that breath sounds were audible, though of diminished intensity, and the fact that no persistent wheeze was demonstrable on that side influenced some to doubt the presence of diffuse airway obstruction in the right lung. The quantitative physiologic data shown in Table I revealed a quite marked diminution in the maximum breathing capacity, slight increase in residual air, but a striking interference with ventilation and oxygen uptake and carbon dioxide output on the right. The bronchspirometric tracings showed that although the right lung could take in air, it trapped this air and it was only during subsequent breaths that the air was finally expelled from the right lung.

An examination of the arterial blood obtained during exercise showed some degree of arterial unsaturation. We believed that these data clearly demonstrated the presence of some sort of an obstructing mechanism in the airways diffusely distributed throughout the right lung. In view of the bronchoscopic findings, it was apparent that the branches of the bronchial tree distal to its main divisions must be the site of this obstruction. Since the lung was virtually nonfunctioning, it was decided to change the therapeutic program from pneumothorax to a pneumonectomy.

This was done and the resected lung showed a moderately severe tuberculous bronchitis involving most of the divisions of the right airway, beginning in the secondary bronchi at a point distal to the areas that could be visualized by the bronchoscopist. This case demonstrates the manner in which physiologic examination may disclose unanticipated findings of importance. Pneumothorax would have eventuated in an unexpandable lung and possibly empyema. A pneumonectomy, which on clinical grounds alone may have appeared wasteful of good lung tissue, actually destroyed little useful lung and avoided a long, hazardous and likely fruitless form of treatment.

CASE 7.—F. C. is a 21-year-old woman who first developed bilateral tuberculosis at the age of 16 years. Originally the disease was most extensive on the left, but this cleared leaving behind scattered linear and nodular scars. At the time of our study, two large cavities and scattered densities were seen throughout the right lung as shown in Fig. 7. After an adequate period of bed rest and an ineffective right pneumothorax without improvement, other therapy was advised.

Because of the extent of the disease in the right lung, it was felt that a pneumonectomy would be the treatment of choice. Preresection studies in our laboratory disclosed the data shown in Table I. The large extent to which the right lung participated in ventilation and oxygen uptake was surprising. A lateral film showed the two cavities to be located in the superior segment of the lower lobe and in the posterior segment of the upper lobe. This case demonstrates the degree to which observation of a roentgenogram can be misleading, especially when only the conventional posteroanterior view is considered. Because of the large extent to which the right lung participated in respiration, it was deemed unwise to sacrifice the entire lung until other methods less likely to destroy the lung had been tried in an attempt to control the disease. Monaldi drainage of the upper cavity and a pre-Monaldi thoracoplasty over the lower cavity were accompanied by cavity closure and conversion of the sputum.

CASE 8.—This 27-year-old woman was given a pneumothorax on the right side which became complicated by an effusion and was abandoned at the end of one year because of obliteration of the space. Subsequently, she had a cavity in the left lung for which a pneumothorax was instituted with exactly the same results. A cavity had persisted at the left apex. She complained of dyspnea on moderate exertion but on a clinical basis was considered to be an acceptable surgical risk for a left thoracoplasty.

Fluoroscopy disclosed marked restriction of motion of both hemidiaphragms and ribs. The degree of pleural involvement is shown in Fig. 8. The physiologic data are shown in Table I. The normal volume of residual air suggests that there is no significant degree of

The nearly fatal effect of the onset of menses is of practical as well as physiologic importance. We have repeatedly been told by women, whose breathing reserves are low, that dyspnea is more severe in the first day before the onset of menstruation and persists thus for two or more days. Menstrual turgescence of the bronchial mucosa⁷ may play a part in this phenomenon. Had we avoided decostaliation of such a large area and had the operation been timed to take advantage of the intermenstrual period, we believe the operation would have caused much less severe respiratory distress.

CASE 9.—S. A. was a 50-year-old man with extensive bilateral tuberculosis. He was unusually apprehensive; because of the extent of the disease and the complaint of dyspnea on exertion he was thought by some on clinical grounds to be a prohibitively poor risk for bilateral surgical collapse. The physiologic data, shown in Table I, disclosed a maximum breathing capacity considerably larger than anticipated and no evidence of diffuse obstructive emphysema.

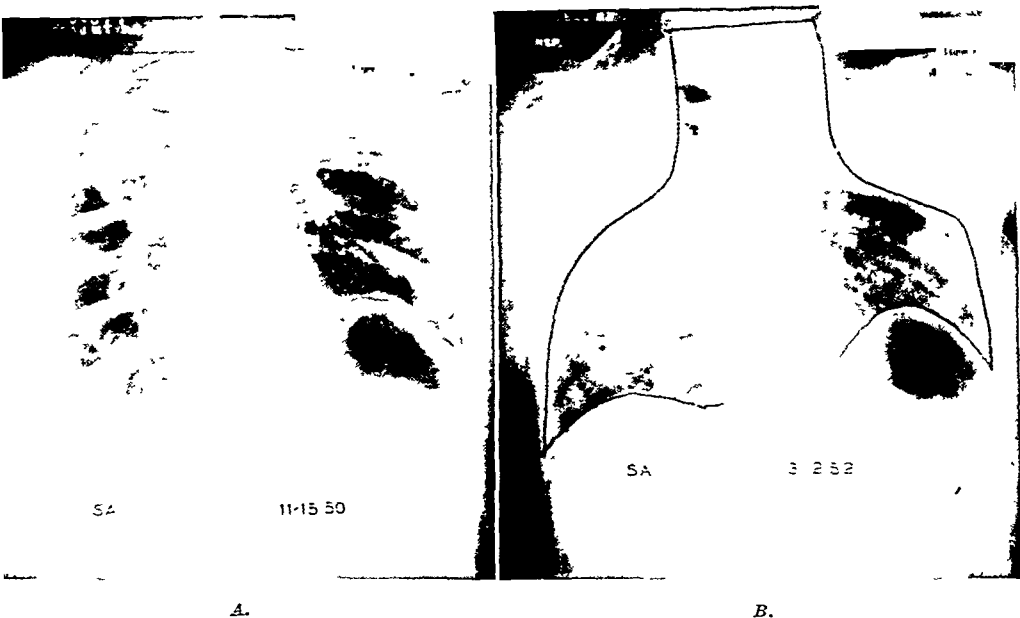


FIG 9 (Case 9).—S. A. a 50-year-old man; bilateral cavitory disease three years; pneumothorax three years; temporary phrenic, left; diabetes mellitus A, Nov. 15, 1950, extensive bilateral disease; elevation left diaphragm. B. Jan. 12, 1952, appearance after five-rib extraperiosteal thoracoplasty with Lucite plombage on left, with subsequent removal of Lucite spheres and ribs. Later, similar procedure on right. Sputum negative on culture.

Because a conventional bilateral thoracoplasty would require more stages and would sacrifice more lung tissue with a less satisfactory collapse than can be obtained by extraperiosteal plombage and subsequent removal of the plomb and overlying ribs, we chose to carry out the latter procedure in this particular case. An extraperiosteal Lucite plombage with subsequent removal of five ribs was performed on the left with no appreciable loss of function. This encouraged us to carry out a similar procedure on the right (Fig. 9).

In so far as the postoperative periods are concerned, none was characterized by unusual distress. The physiologic data disclose that the thoracoplasty on the right was followed by a considerable drop in the maximum breathing capacity. Unfortunately, our final studies had to be made only ten weeks after the last operation. We would expect the maximum breathing capacity to be somewhat higher after a longer recovery period. The diseased area on the right was surrounded by a larger amount of aerated lung than that on the left; hence, the

emphysema present. The low maximum breathing capacity we believed to be due to the marked restriction of thoracic expansion consequent to the pleural membrane. This is also indicated by the very small total volume of the lung. We believed that thoracoplasty on the left could be carried out even though the left lung participated to a normal degree in respiration. Because of the bilateral pleural envelope and the knowledge that much greater force than normal was required in order to bring about ventilation in both lungs, we stated that the thoracoplasty should be done in small stages, every effort being made to keep the area of denuded chest wall as small as possible.

At the first stage of the thoracoplasty one of us removed the entire first and second ribs, including the cartilage, and a posterior segment of the third rib to the anterior axillary line. Moderately severe paradoxical motion of the denuded area promptly developed, but she was able to maintain adequate ventilation, and the distress was not intolerable or extremely alarming, until with the onset of menstruation she deteriorated very abruptly. During the first two days of menses, respiratory efforts were more marked and in spite of maintenance in an oxygen tent and efforts to immobilize the chest wall, it was not believed that she would survive this period. Gradually the paradoxical motion lessened somewhat but she remained dyspneic at rest.

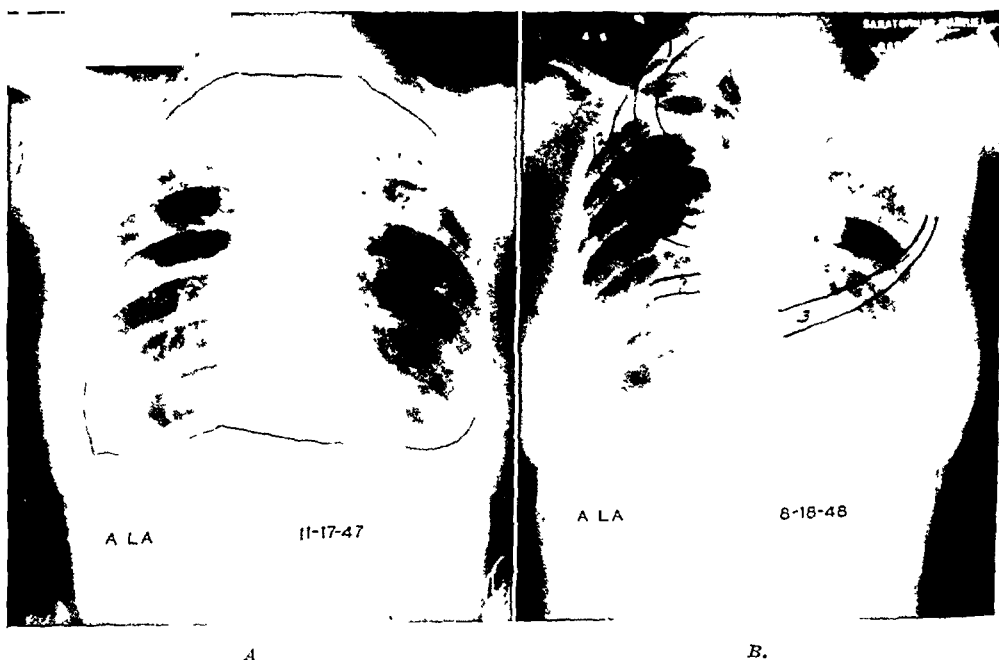


Fig. 8 (Case 8)—A L was a woman 27 years old; curing for five years, bilateral disease, bilateral cavities, successive pneumothorax each side; in each instance fluid formed and pneumothorax was abandoned. Dyspnea on slight exertion for four years. A, Nov. 17, 1947, bilateral disease, cavity left apex, obliteration of costophrenic sulci. B, Aug. 18, 1948, first-stage two and one-half rib thoracoplasty, left, Aug. 5, 1948. Note extent of anterior decostalization.

Fluoroscopy approximately one month after the operation clearly demonstrated the marked paradoxical motion of the chest wall, the underlying tissues moving en masse to the right side during inspiration and back again during expiration. The mediastinum moved quite far to the right on inspiration and returned to the midline during expiration. In this particular patient removal of the second rib and cartilage along with the first rib and cartilage decostalized more than two thirds of the anterior chest wall down to a level opposite the posterior end of the ninth rib. The mechanism of the paradoxical motion of the chest wall is obvious.

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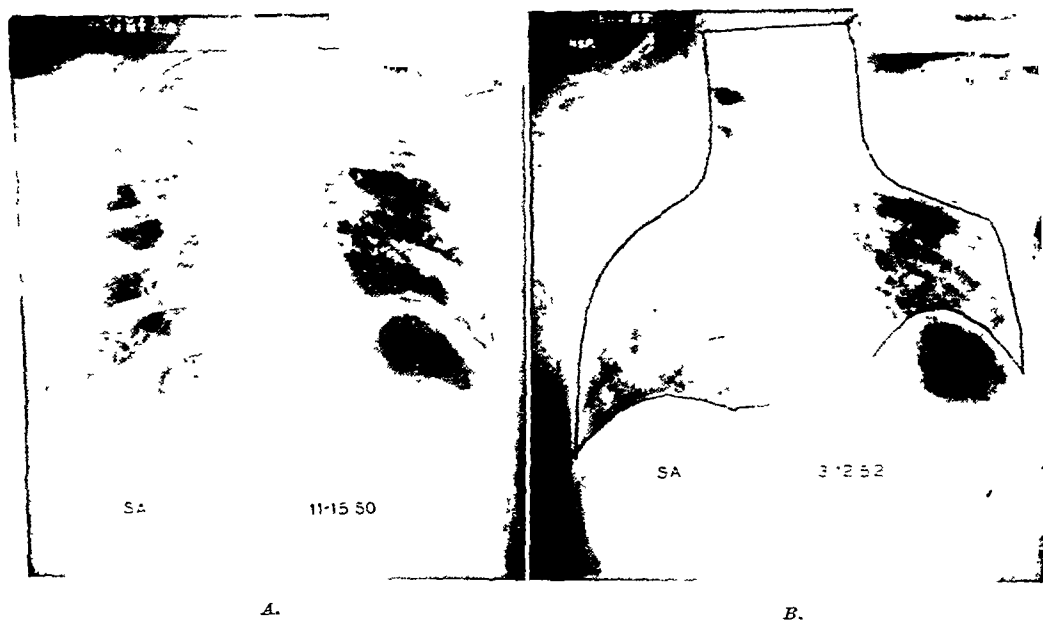


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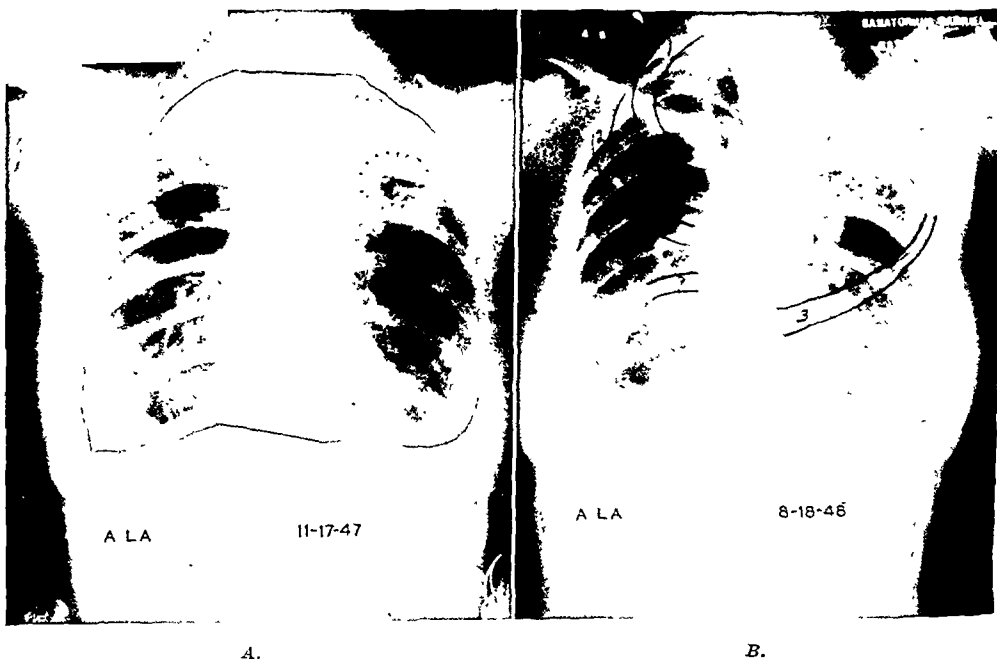


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7. The lung per se is an enormous capillary bed, suspended in air, which can transmit a widely variable volume of blood with relatively slight changes in pulmonary artery pressure.

8. The body is possessed of an adaptive mechanism whereby circulation is shunted from a collapsed or diseased area to a more normal area. Poorly or unventilated but still distended portions of lung have a diminished pulmonary capillary blood flow.

9. The remarkable degree to which the pulmonary capillary bed can be enlarged by increase of cross-section area of the capillaries and perhaps by opening of previously nonperfused capillaries is demonstrated by the fact that, when both lungs are approximately normal, ligation of a pulmonary artery to one lung causes only transitory elevation of the pulmonary artery pressure.

10. Pulmonary function studies are valuable adjuncts in the over-all assessment of an individual prior to thoracic surgery and are necessary in borderline cases. Such studies are of value in helping to determine the patient's ability to withstand a particular procedure and also in determining which procedure is likely to be best tolerated. The more limited a patient's respiratory reserves, the more important it becomes to know the type of limitation and its extent.

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DISCUSSION ON "BILATERAL BRONCHIECTASIS: A CLINICAL AND PHYSIOLOGIC EVALUATION OF THE RESULTS OF SURGICAL TREATMENT," BY DR. EDGAR P. MANNIX, JR., DR. FRANCIS S. GERBASI, DR. CHARLES E. O'BRIEN, AND DR. RICHARD H. ALDER, DR. W. ARNOLD MC ALPINE, AND DR. HARPER KERR; AND "DECISIONS IN THORACIC SURGERY AS INFLUENCED BY THE KNOWLEDGE OF PULMONARY PHYSIOLOGY," BY DR. WARRINER WOODRUFF, DR. CARL G. MERKEL, AND

DR. GEORGE W. WRIGHT

DR. FREDERICK G. KERGIN, Toronto.—I should like to discuss Dr. Mannix's paper, and I wish to compliment him on what I think is a very important investigation of an important subject. It is true, as he suggested, that we have had some interest in bilateral resections and we have a group of some fifty patients who have had bilateral resections in the past. Our

drop in maximum breathing capacity after the second thoracoplasty may have been due chiefly to a greater collapse of healthy lung tissue. It is also possible that interference with the leverage mechanism of chest-wall motion may have been an additional cause.

It has been our experience that bilateral thoracoplasty, regardless of how it is performed, nearly always causes more drop in the maximum breathing capacity after the second side is done than after the first. This case demonstrates that quantitative measurements may correct an erroneous impression of respiratory impairment which has been based on clinical grounds alone. It also demonstrates the utility of extraperiosteal plombage. We have been using extraperiosteal Lucite plombage with increasing frequency in poor-risk patients since its introduction for this purpose by Dr. Elliott Michelson, in 1949, at the Veterans Administration Hospital at Sunmount, N. Y.³

As a result of our studies and observations in this field, we have found the following concepts to be practical and helpful guides in making surgical decisions on patients with respiratory problems:

1. The lungs are passive structures in so far as air movement is concerned. Under natural conditions air movement is entirely a result of and directly proportional to the changes in the volume of the thorax, caused by movement of the thoracic parietes.

2. The lungs and thorax act as the "pump" which brings air to the pulmonary capillary bed for gaseous exchange. It is the mechanics of this "pump" with which we are primarily concerned.

3. In the normal individual, the factor limiting peak physical exertion is not the "air pump" but the cardiovascular system. The normal person is endowed with far greater respiratory powers than circulatory abilities.

4. Because of the tremendous pulmonary reserve, there can be extensive pulmonary damage without critical respiratory limitation. For instance, the untrained normal man can augment oxygen uptake to a level of eight to ten times that used in the resting state. For short periods of time the volume of respired air can be increased fifteen- to twenty-fold. Cardiac output, however, can be increased only four or five times.

5. The capacity of the respiratory apparatus to pump air is dependent upon many factors. Among these are:

- (A) The integrity of the thoracic parietes. Any factor damaging them and diminishing their ability to move will diminish the effectiveness of the pump as a whole. Causes for impairment are: (1) defect of chest wall; (2) restricting pleural membrane; and (3) neuromuscular impairment, such as phrenic paralysis or intercostal pain.

- (B) Unimpeded airways, not only in the major bronchi but, even more important, in the smaller bronchioles.

- (C) Compliance of the lung. Any factor decreasing the distensibility, be it inflammation, edema, fibrosis, or emphysema, will impair the action of the pump, depending upon the degree of involvement.

6. The lungs seem to be capable of considerable overdistention before showing appreciable signs of functional impairment. This has a direct bearing upon the question of collapse therapy following resection.

We have developed a concept of pulmonary segments, and Dr. Boyden has numbered those segments, as you all know, ten on the right and eight on the left. Most of the patients shown by Dr. Mannix had entire lobectomies of the lower lobe, probably because all segments were involved. However, it is still widespread practice to take the superior segment of the lower lobe whether or not it is involved, and we know too that it will occasionally be involved.

No one has emphasized that the superior segment of the lower lobe is of large volume with three subsegments, each of which approximates in volume any single basal segment. I think that in the ten segments on the right, nine of those should be given the value of one, but the superior segment of the lower lobe should be thought of as a unit of three, so far as volume goes. Therefore, if in bilateral lobectomy the superior segment, although free from disease, is taken on each occasion, in my opinion the equivalent of six of the smaller segments is avoidably lost. Preservation of this amount of normal lung is of tremendous functional importance, especially where the extent of necessary resection reduces respiration to a marginal capacity.

DR. ROBERT T. FOX, Evanston.—I wish to discuss Dr. Woodruff's paper. At the Municipal Tuberculosis Sanitarium in Chicago, we too are faced with a certain group of far-advanced bilateral cases who can be brought along just so far on bed rest, chemotherapy, and the various inflation collapse measures, and then are offered no hope unless surgery can be done. Many of these have to be turned down for surgery because they have too much disease. Evaluation of the borderline cases is frequently helped considerably by a program such as Dr. Woodruff has mentioned; in fact, our program was set up and is operated by Dr. Gordon Snider, one of the disciples of Dr. Woodruff and Dr. Wright, and includes exactly the routine that Dr. Woodruff has outlined.

(Slide.) This case involves a Negro woman with very extensive bilateral disease.

(Slide.) After about a year and one-half of bed rest, pneumoperitoneum, and all the chemotherapy we have today (including a fairly long course of Isoniazid) the right side appeared almost completely healed, with a good-sized cavity remaining on the left and disease lower down. Unfortunately many of these patients have so much distortion of the bronchial tree that bronchspirometry is impossible or inconclusive, and that was true of this patient, but fluoroscopically we obtained some inferential knowledge as to the function on the left side.

(Slide.) She had a pneumonectomy and has done very nicely. The preoperative work-up shows information that led us to believe she was a fit candidate for resection, even without really accurate bronchspirometric data, and it was the clinician's feeling that 60 per cent of function was on the right side. The postoperative studies have not yet been completed.

(Slide.) Here is another case. This was in 1945 and there is a huge cavity on the right side in this patient. She had a right thoracoplasty in 1946.

(Slide.) She was discharged, but some four years later the disease flared up on the left side. She was treated for some time with chemotherapy and pneumoperitoneum and still has a huge residual cavity. The question is, Can she tolerate resection on the left? She did have a left upper lobe lobectomy and has done very well.

(Slide.) Again bronchspirometry was inconclusive but on fluoroscopic evidence we felt that she could tolerate the resection. Postoperative condition is good. Again, the postoperative studies have not been completed.

We have found that these tests bring into the surgical field a certain number of patients who we have felt were not fit candidates without such careful evaluation.

DR. GEORGE W. WRIGHT, Saranac Lake, N. Y.—I should like to discuss Dr. Mannix's paper. There is one point of presented data which I think requires some explanation and emphasis. The general use of the ratio between the residual capacity and the total capacity I think can be most misleading. It is well demonstrated that in diffuse obstructive emphysema this ratio is increased, and hence we are likely to believe that whenever the ratio is increased there must be diffuse obstructive emphysema. When resections are done with some loss of

interest is primarily in two questions. It seems remarkable that after the more than twenty-five years that we have been doing lung resections, there are some fundamental questions that are still open and unanswered.

One question which is unsolved is whether in fact it is deleterious to the function of a lobe to allow or encourage it to overdistend; second, does that overdistention eventually lead to emphysematous changes and progressive loss of function? We have recently called in eleven patients, who had extensive bilateral resections from four to eighteen years ago, and have done functional studies. I think we can sum our results up by saying that if these patients show on the average 50 per cent of normal function, they do not complain of shortness of breath. They are short of breath on exertion but they have become so accustomed to sparing themselves that they seldom have to complain of that.

Perhaps our most illuminating case concerns a patient who is now 40 years of age, who had resections of the lung sixteen years ago by Dr. Shenstone and Dr. Janes. This woman, starting eighteen years ago, over a period of two years had resections of the right lower lobe, the left lower lobe, and the right middle lobe, in three stages by the tourniquet technique and after each stage had an empyema and fistula. She remains perfectly well, carrying on, and tests of this patient are perhaps worth mentioning. Maximum breathing capacity now is 52 per cent of normal, vital capacity is 66 per cent normal, functional residual capacity is 2,810 c.c., and residual nitrogen is 2.1 per cent. So far as we can determine she is not as yet going on to a true disabling emphysema.

DR. ARTHUR H. AUFSES, New York.—I would like to present a case which concerns a patient with extensive bilateral resection for bronchiectasis who had an unusual postoperative complication. This patient was a girl, aged 22, who was seen first in 1947 with severe bilateral bronchiectasis and a very severe paranasal sinusitis. We treated the sinusitis for a time and tried to reduce the expectoration with antibiotics, both parenterally and by instillation through catheters, and finally we operated upon her when the sputum had diminished.

(Slide.) This shows extensive bronchiectasis in both lower lobes, and at this time we thought that the right middle lobe was normal, but it was probably due to a poor bronchogram.

(Slide.) This shows the disease in the lingula on the left side; a few bronchi in the left upper lobe were also involved. We thought we would have to excise the left lower lobe and lingula and then perform a segmental on the right lower lobe. At this time the left lower lobe and lingula were resected, with an uneventful postoperative course.

(Slide.) She returned six months later, and now the bronchograms demonstrated that the right middle lobe, which we thought was free of disease, was also involved.

(Slide.) Here you see the right lower lobe; the basal segments are involved, also the right middle lobe and a small segmental involvement of the right upper lobe. The apical and subapical segments of the right lower lobe were considered to be uninvolved. She was again prepared and this time we performed a right middle lobe lobectomy and a segmental resection of the basal segments of the right lower lobe, leaving the subapical and apical segments of the right lower lobe in situ. For seventy hours after operation this girl had such terrific dyspnea that she went into pulmonary edema. The character of the sputum was not purulent, but was the typical foamy exudation of pulmonary edema. This was treated by the removal of salt from the food and parenteral fluids. She came out of this pulmonary edema after forty-eight hours and from then on made an uneventful recovery.

Two years later we had a bronchspirometric examination performed and at this time she had 2,200 c.c. vital capacity and a maximum breathing capacity of 56 L. She is not dyspneic on ordinary activity. The only trouble at present is that the sinusitis still flares up, and she has upper respiratory infections with a considerable amount of expectoration.

(Slide.) This is a roentgenogram taken a couple of months postoperatively, and the condition has remained practically in this state until the present time.

DR. B. H. RAMSAY, Los Angeles.—I should like to discuss Dr. Mannix's paper (which was excellently presented and very interesting) and to make only a single remark.

apical segment should be preserved whenever it is free of disease, particularly in those patients who are to have bilateral resections. I think that this particular patient is an example of one who had progressive bronchiectasis, eventually having lesions in several segments of the remaining lung on each side. It is difficult to state whether or not he would have survived, even if the apical segment had been spared.

DR. WRIGHT (Closing).—I should like to make a comment on the question of overdistention. This question has been before this Association almost every year since resections were first begun. We are beginning, I believe, to have some information of value. So far as the immediate effect of overdistention is concerned, one should bear in mind that overdistention is a relative matter. The simple procedure of going from the recumbent to the erect position doubles the size of a person's lungs; in other words, there is a 100 per cent overdistention.

There is a very wide range through which the lung can be varied in its size or its degree of distention with no measurable or discernible evidences of impaired function. There is, however, a degree beyond which the lung cannot be distended without having some loss or impairment of function. The late results are of course extremely important, particularly in the light of the work presented before this Association some years ago by Dr. Longacre, in which he believed that in animals, dogs particularly, he had shown that prolonged overdistention led to development of diffuse obstructive emphysema. Dr. Kergin made a very good point; does this occur in human beings. The only thing I can tell you is that if a normal perfectly healthy lung is overdistended within what would appear to be a reasonable physiologic range, we have been unable to discern any evidence of diffuse obstructive emphysema. I have had under observation two patients who have had autolobectomies (by that I mean both upper lobes markedly contracted so that the hilar shadows actually dangled in the apex). There is only a lower lobe left on either side. Neither of these patients shows anything that is remotely the same as the physiologic data we see with diffuse obstructive emphysema. So at least I can say that I know of two people who have prolonged lobar overdistention but who do not have diffuse obstructive emphysema.

lung tissue it must be borne in mind that the total capacity can be reduced, the residual capacity remaining normal, leading to the same kind of abnormal ratio that occurs in diffuse obstructive emphysema, although actually there is no diffuse obstructive emphysema.

I should like to ask Dr. Mannix, therefore, whether or not in these patients, who show an abnormality of the residual capacity-total capacity ratio, the absolute residual capacity was increased. This is the measurement that is most useful.

The second thing I would like to ask is the amount of good lung tissue that was removed in the cases that did poorly postoperatively. In our series of bronchiectasis cases those who showed rather marked disturbance of respiratory function after the operation always had severe damage before the operation. If good lung tissue is resected the reserves are already so low that the loss of relatively small amounts of good lung tissue is much more damaging than the same amount of lung tissue resected in a patient with a large reserve. Therefore, I would like to have some notion of how much reasonably good lung tissue was sacrificed at the time the resections were done.

DR. MANNIX (Closing).—I wish to thank the discussors. With regard to the comments of Dr. Kergin and Dr. Wright on overdistention, we appreciate that this is one of the mechanisms by which the remaining pulmonary tissue fills the pleural space after resection, and that there are some patients who have neither subjective nor objective evidence of respiratory disability. We do not wish to imply that postoperative overdistention of the lung is as handicapping as true obstructive emphysema. We do believe, however, that postoperative overdistention is likely to produce additional disability in those patients who already have obstructive emphysema or asthma. Also, there may be a level beyond which, for any one patient, progressive overdistention of otherwise normal remaining lung parenchyma produces significant respiratory insufficiency. In one of our patients, who has only five segments remaining, and no obstructive emphysema or asthma, increasing residual air over a period of several years following bilateral resections was associated with falling arterial oxygen saturation. At the same time the patient was complaining of increasing dyspnea. We do not know the explanation for this hypoxemia. There may have been a disturbance in oxygen gradient independent of, or due to, marked overdistention of the lung. This concept is speculative, since our studies did not include measurement of alveolar and arterial oxygen tensions.

Concerning Dr. Aufses' patient, I wonder whether or not the improvement which occurred physiologically later on could have been due to disappearance of bronchial or bronchiolar spasm, which was present in the immediate postoperative period. I wish to illustrate the importance of bronchiolar spasm in this respect by citing a case. The patient had asthma and a very low pulmonary reserve. A bronchiogenic carcinoma was present in the anterior segment of the right upper lobe. When the patient was induced with ether, which is an agent which ordinarily dilates the bronchial tree and which actually has been used in the past to treat status asthmaticus, the patient was thrown into an attack of severe bronchiolar spasm, with inadequate ventilatory exchange. The operation was cancelled. The patient was successfully induced one week later, using an agent which is said to induce bronchospasm, namely, cyclopropane. A right upper lobectomy was uneventfully accomplished. Bronchiolar spasm returned after operation but this was satisfactorily treated. It is well known that the anesthetic agent may produce spasm of the bronchial tree in both asthmatic and nonasthmatic patients.

In answer to Dr. Wright's question about whether or not the total residual air was increased, these data are recorded in the submitted manuscript. It is my strong recollection, however, that the total residual air was increasing in all patients whom we had an opportunity to study on more than one occasion after resection.

Concerning the amount of normal lung tissue which was removed, there was a period at Ann Arbor when some concern was felt about leaving the apical segment of the lower lobe. The patient who died thirty-four months after operation had a lower lobectomy on one side, although the apical segment was not involved. I agree with Dr. Ramsay that the lower

considerably of the accepted method of commissurotomy for mitral stenosis, and also of mitral suturing for regurgitation. Swan⁵ considers it to be a modification or extension of his original technique. In patients where the defect is very low, as in cases of persistent ostium primum, we have added the principle of anterior-posterior approximation of the auricle which was first presented by Murray.³ In other words, the present concept and technique of atrio-septo-pexy embraces freely those intracardiac techniques which aid in the successful accomplishment of its aim—the complete anatomic and physiologic separation of the systemic and pulmonary venous systems

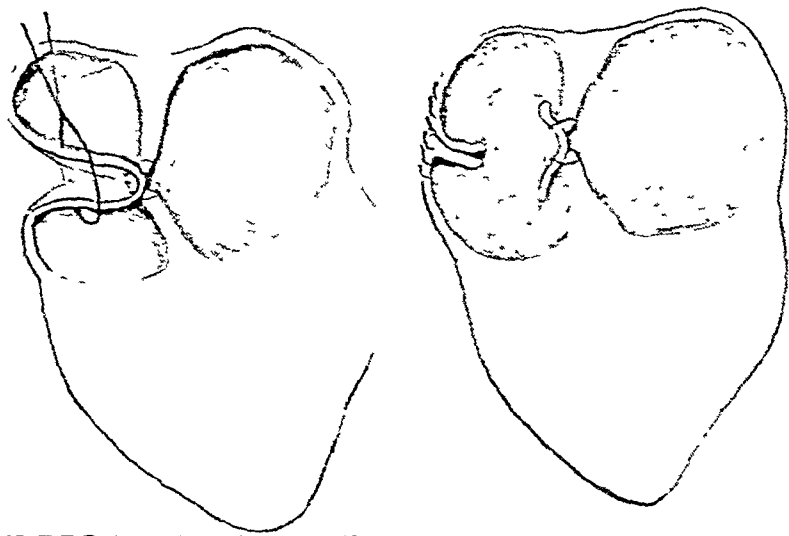


Fig. 1.—Cohn's method of repairing experimentally produced atrial septal defects by applying a patch of the atrial wall over the defect.

Murray³ was the next to propose (1948) a method for the closure or at least the reduction in size of atrial septal defects: his procedure consisted of passing long threaded needles from the anterior to the posterior atrial walls in the region of the septum. By tightly tying the mattress sutures so placed, he brought the anterior and posterior atrial walls closer or even actually together. (Fig. 2.) The main disadvantage of this method was its inaccuracy, guided, as it was, merely by the recognition of certain externally located landmarks. It is our belief that the addition of intracardiac digital "vision," by insertion of a finger through the right (or left) auricular appendage, renders this a valuable surgical method particularly as an auxiliary technique in closing very low defects. It may perhaps prove independently corrective in cases of very large septal defect or of single atrium.

Swan and his co-workers,⁶ in 1950, suggested the simultaneous invagination of both auricular appendages after passing a threaded curved probe from one appendage tip to the other via the defect. Plastic buttons threaded upon

ATRIO-SEPTO-PEXY FOR INTERATRIAL SEPTAL DEFECTS

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SINCE the first presentation (June, 1952) of the concept and the first application of atrio-septo-pexy for the surgical correction of abnormal interatrial communications,¹ considerable additional experience has been gained in surgically treating such patients. While the original basic concept has proved to be sound, certain technical variations have been developed in order to manage the different clinical variants of this situation. Thus our original method has been modified in cases presenting the additional abnormality of anomalous entrance of some or all of the pulmonary veins into the superior vena cava or directly into the right atrium. Very low defects of the persistent ostium primum type have been proved to be amenable to this technique. The coexistence of acquired mitral stenosis (Lutembacher Syndrome²) in certain of these cases has proved no serious obstacle to successful simultaneous surgical correction of both conditions. Only patients with essentially a single atrial chamber have so far seemed completely unsuitable for correction by atrio-septo-pexy. It is believed that an extension of Murray's³ original technique of suturing the anterior and posterior atrial walls together (with the addition of intra-auricular digital guidance) may accomplish anatomic and functional separation of the single atrium into two chambers.

HISTORICAL

Cohn,⁴ in 1947, first showed experimentally that artificially created interatrial defects could be closed by invaginating and suturing a portion of the right atrial wall to the auricular septum; subsequently the invaginated portion was cut off to leave a patch over the defect. (Fig. 1.) Simultaneously the remaining atrial wall was repaired by previously placed mattress sutures. There were three obvious disadvantages. This method, as proposed, did not primarily completely close the defect since the atrial patch was only actually approximated to the septal edge in four places (at each quadrant). The external surface of the atrial patch placed within the blood stream carried with it the threat of intra-atrial thrombosis. The excision of a portion of the atrial wall implied the possibility of serious or even of exsanguinating hemorrhage. It is not known whether Cohn's method was ever actually employed in a human being.

Some have considered the operation of "atrio-septo-pexy" as a modification of Cohn's procedure. It is obvious that some similarity in concept exists. However, atrio-septo-pexy, embracing, as it does, digital guidance of the suturing by a finger inserted through the right auricular appendage partakes

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Merendino and his associates⁷ reported in 1951 an experimentally successful technique of closure of auricular septal defects in animals using a small bag or tampon created by suturing autogenous fat within a pericardial sac. This tampon was tightly drawn against the septum and partly into the defect by traction upon a suture passed through the defect and the opposite atrium. (Fig. 7.)

Hufnagel and Gillespie,⁸ in 1951, reported an ingenious method and an instrument capable of applying the two halves of a plastic button respectively

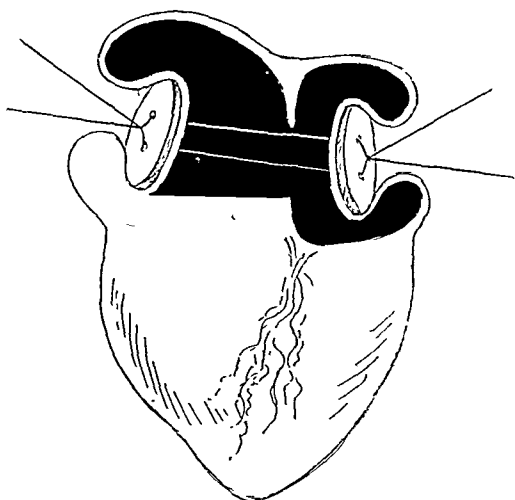


Fig. 3.

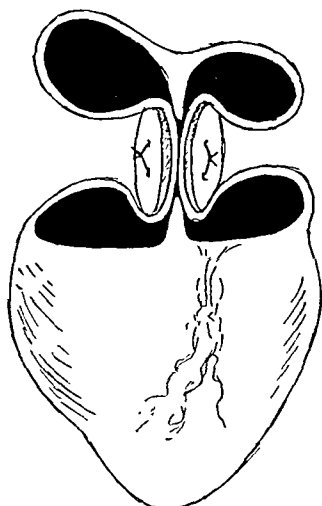


Fig. 4.

Fig. 3.—Swan's method of invaginating the atrial appendages upon plastic buttons.
Fig. 4.—Inverted appendage approximated against atrial septum.

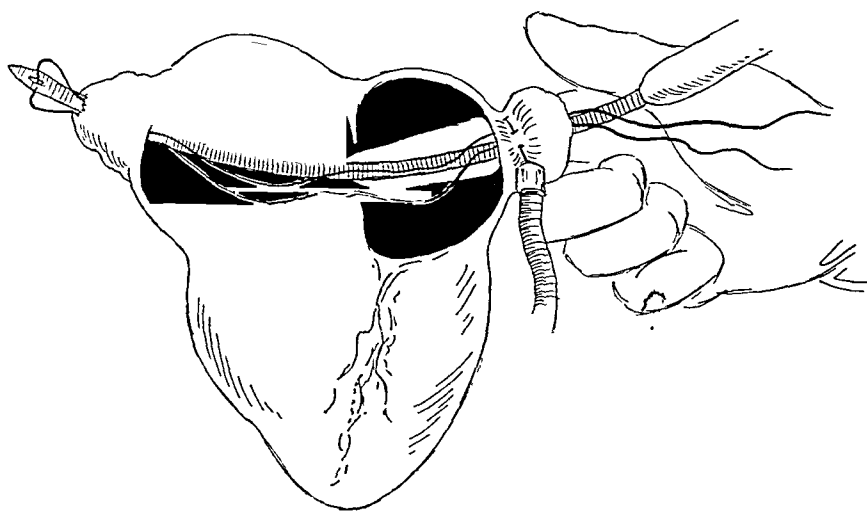


Fig. 5.—Digital guidance of probe passed through septal defect in performance of modified Swan procedure.

the transatrial sutures were approximated by tightly tying the sutures. (Figs. 3 and 4.) One of us (C. P. B.) subsequently reported a modification of this technique¹ using a finger inserted through the left atrial appendage to directly guide the passage of the probe. (Fig. 5.) Experience with six patients operated on by this method (with two operative deaths and no instance of complete abolition of the shunt) convinced us that this method, so successful in correcting experimentally created defects, was unsatisfactory for human application.

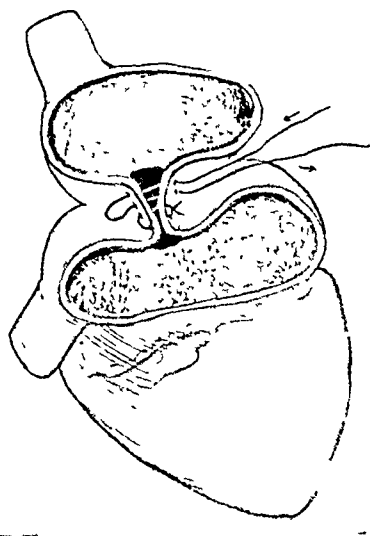


Fig. 2.—Sagittal section showing Murray's method of anterior-posterior approximation of the atrial walls to reduce the size of an atrial septal defect

The major deficiencies of the method are related to: 1. The danger of too greatly reducing the size of the usually small left atrial chamber by the invagination of the left auricular appendage or wall upon a plastic button. This is particularly likely when a very large defect exists requiring application of a large button for its closure. 2. The invaginated appendages (Fig. 6) do not necessarily grow attached to the edges of the septal defect even though they may grow to each other. This failure is again more likely in large defects. Under such conditions the effective size of the defect and its consequent shunt might be reduced but would not be abolished. 3. In persistent ostium primum the low application of the invaginated appendages might encroach upon the entrance to the mitral valve. In any event, it is apparent that defects of this type can never be completely closed by this technique.

Dodrill¹⁷ suggested the use of excluding rings on an ice-tong arrangement to temporarily approximate the two atrial walls of the septum. Either atrial wall could be opened in this area to permit creation and suture repair of an atrial defect under direct vision. He also suggested that very large defects might be bridged by suturing the left atrial wall to the periphery of the defect.

of a persistent ostium primum is not to be expected. The polythene material subsequently becomes covered over by endothelium derived from the edges of the septum.

We freely admit that this is one of the two acceptable surgical approaches presently capable of effecting complete surgical closure in cases of interatrial septal defect. However, a limited experience with this method in the laboratory leads us to the conclusion that it is a complicated technique entailing many inevitable risks and hazards. Not only is there risk of serious hemorrhage and of possible air embolism (because of the open technique) but there are inherent risks of either under- or overheparinization of the blood. The use of foreign material (polythene) to replace the lack of cardiovascular sub-

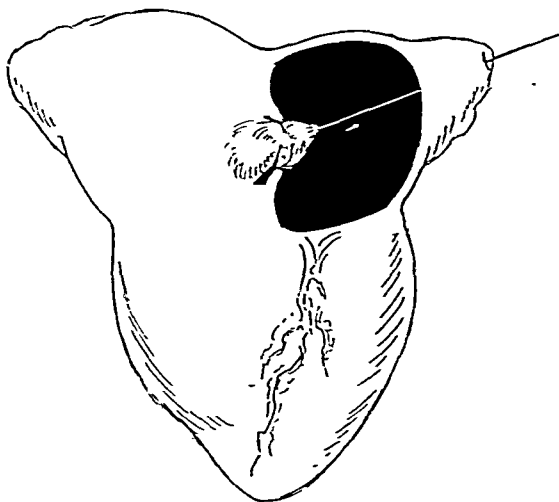


Fig. 7.—Merendino's method of plugging an atrial septal defect by use of pericardial bag of autogenous fat.



Fig. 8.—Hufnagel's buttons closed about septal defect.

to the opposite sides of artificially created septal defects. By turning the handle of the instrument, the two sides of the button become tightly screwed together. (Fig. 8.) While this technique worked well in artificially created defects, Gross and his associates^{9, 10} had poor results in applying this technique in human beings.

Gross^{9, 10} has devised an open method of direct intracardiac suturing which he has applied in cases of auricular septal defect. He has reported two operative survivals and four deaths.



Fig. 6.—Autopsy specimen (human) obtained three weeks after performance of Swan procedure for large atrial septal defect. While inverted appendages might have become adherent to each other, it is evident that adherence to the septal edges would never have occurred.

The technique depends upon the hemostatic suturing of a latex or plastic “well” to the side of the dilated right atrium. An incision is then made within the portion of the atrium circumscribed by the base of the “well.” Blood emerging from the atrial incision fills the “well” to a depth corresponding to the intra-atrial pressure, usually about 10 cm. Local heparinization prevents clotting.

While direct ocular visualization of the defect is not possible by this technique, passage of palpating fingers through the auricular incision permits tactile or digital “vision” of the type so useful in closed intracardiac surgery. Small defects can then be directly sutured by the sense of touch. Gross uses patches of polyethylene sheet material to span larger defects, suturing the edges of the patch to the edge of the defect. He feels that this method is generally applicable in all cases of auricular septal defect, but feels that complete closure

right atrial chamber which facilitates extensive invagination. So far we have observed no need for such further enlargement of the already greatly dilated right atrium, even in small children. It probably needlessly complicates a relatively simple technique. Furthermore, there is question whether blood exposed to an atrial wall partially composed of pericardium might not undergo thrombosis. However in very young infants such an artificial enlargement of the right atrium might be very helpful.

CONCEPT AND PRINCIPLE OF ATRIO-SEPTO-PENY

In its most extreme simplification, the interatrial septal defect represents a lack or dearth of cardiovascular tissue in the partition which separates the primitive atrium into its two mature subdivisions. This causes certain untoward effects upon the circulation, chiefly because the pressures normally existing in the two atria are not equal. In most uncomplicated cases the pressure in the left atrium is higher than that in the right. Hence, in the absence of complete continuity of the interatrial septum, considerable blood will flow from the left atrium into the right. It is then necessary for it to traverse the right ventricle and the pulmonary circulation before it can again reach the left atrium. Here a portion will again cross the septum to retrace its passage through the pulmonary circuit, while the remainder enters the left ventricle via the mitral valve to contribute to the systemic arterial circulation. In some cases, the blood must pass through the pulmonary circulation several times for each passage through the aorta.

The exact statistical relationship of blood flow in the two circulations (beautifully demonstrable by cardiac catheterization) is dependent upon the size of the defect and upon the relative pressure differential existing between the two atria. The latter is influenced by the coexistence of other circulatory abnormalities, such as mitral stenosis or regurgitation (higher left atrial pressure), pulmonic stenosis (higher right atrial pressure), or high pulmonary vascular resistance (higher right atrial pressure).

When the right atrial pressure is higher than the left, the shunt is, of course, from right to left and unoxygenated blood enters and becomes mixed with the arterial blood of the systemic circulation. This produces an oxygen undersaturation in the systemic arteries, and, if large, causes visible cyanosis.

In many cases, especially those with a large defect, there is both a right-to-left and a left-to-right shunt. Such a double shunt is possible because the different pressure curves in the two atria vary in such a way (during the different phases of respiration and circulation) that the peak pressure in one occurs at a different time from the other. Under such conditions, the major shunt may be in one direction while the lesser one also demonstrably affects the circulation (either higher oxygen content in the right atrium with a major right-to-left shunt, or undersaturation of the peripheral arteries with a preponderant left-to-right shunt).

The relative intra-atrial pressures and hence the direction of the shunt may change under certain conditions such as shock, heart failure, extreme

stance (the defect) raises many theoretical and practical objections. It seems extremely unlikely that other less adept surgeons will ever be able to match the operative results which the master technician Gross may attain.

On Sept. 3, 1952, Lewis and Taufic¹¹ successfully closed an interatrial septal defect in a 5-year-old child using an open technique under hypothermia. Both venae cavae were temporarily occluded and the right auricle was widely opened. The contents of the atrium were aspirated and the defect was closed by suturing under direct ocular vision. The circulation was completely interrupted for five and one-half minutes.

While this was a great and notable accomplishment resulting in complete surgical closure of a large septal defect, it is a method which probably will not be found acceptable for human beings with atrial septal defect. Even before Lewis' case (Aug. 29, 1952) some of us (C. P. B. and H. E. B.) had operated upon a young woman with a large persistent ostium primum type of defect by a nearly identical method. At that time we were of the opinion that atrio-septo-pxy was not applicable in such a case. To our chagrin and dismay, coronary arterial air embolism and ventricular fibrillation ensued, resulting in death upon the operating table.¹² Subsequent laboratory experience with hypothermia and direct open surgery of the heart for interatrial defects has convinced us that the combined method is contraindicated in surgery of the left side of the heart because of this very danger (coronary air embolism). Since an atrial septal defect automatically provides wide opening of the left atrial chamber whenever the interior of the right atrium is exposed, it appears that open surgery under hypothermia (or by use of the heart-lung apparatus) is contraindicated in cases of interatrial septal defect.

On Jan. 11, 1952,¹ one of us (C. P. B.) performed the first atrio-septo-pxy in a 37-year-old white woman (P. F.) using the left index finger inserted through the right auricular appendage to guide the passage of the suturing needle. Subsequently it was possible to demonstrate (by cardiac catheterization) that the defect and large left-to-right shunt had been completely closed. Table I. The patient's previous myocardial insufficiency promptly disappeared.

TABLE I. CATHETERIZATION STUDIES OF P. F.

	PREOP. CATH.	IMMED. P.O. CATH.	3 MO. P.O. CATH.
Pulmonary artery pressure	90-40	45-50/30-35	
Right ventricular pressure	90-10	45-50/0-2	
Right auricular pressure	10-2	10-2	
Pulmonary artery blood flow	17.3 L./min.	5.9 L./min.	
Systemic blood flow	4.1 L./min.	5.9 L./min.	
Left-to-right shunt	13.2 L./min.	0 L./min.	
Peripheral O ₂ saturation	94%	82%	95%

This surgical success and the simplicity and logic of the technique have led us to persist in its application in other cases of interatrial communication.

Schumacker¹³ has modified the original technique of atrio-septo-pxy by suturing a section of pericardium to the lips of a long incision surgically produced in the right atrial wall. This has the effect of greatly enlarging the

heart. It is therefore evident theoretically, as well as clinically, that even complete interruption of the continuity of the normal peripheral blood supply to the circumscribed invaginated portion of the right atrial wall by multiple interlocking mattress sutures does not seriously impair the viability of this segment.

INTRINSIC CONDUCTION SYSTEM

It was feared at first that suturing to the remnants of the auricular septum might produce disturbances of cardiac rhythm and might even completely interrupt the conduction system. These fears have proved largely unfounded. The operative course, in these cases, is rarely attended by any rhythmic disturbance except for an occasional atrial premature contraction.



Fig 9—Showing location of auricular-ventricular node and conduction bundle. While this system may be readily encircled by a suture in the experimental animal, it is easy to avoid it in human beings.

In the experimental animal, however, it is easy deliberately to encircle and to ligate the auriculoventricular conducting bundle (His) close to its origin just anterior to and slightly caudad to the ostium of the coronary sinus (Fig. 9.) Complete auriculoventricular dissociation results with development of an idioventricular rhythm. Sooner or later ventricular fibrillation supervenes with immediate exitus. Such possible inadvertent interruption of the conducting system must, therefore, be carefully guarded against in human beings, especially when dealing with low defects of the persistent ostium primum type.

It is suggested that the operator attempt deliberately to localize the coronary ostium by digital exploration before placing any sutures. He should then keep well cephalad to that area, even if it means failure to completely close a small residual defect in this region. Small persistent residual defects permit small residual shunts but do not preclude an excellent clinical result.

In addition, when placing the lowermost sutures in the closure of these defects, the actual tying down of the knots should be performed gradually

exertion, pulmonary infection, development of pulmonary hypertension, etc. Thus a previously acyanotic case may become cyanotic.

In certain of the afore-mentioned conditions, the defect may have a partially compensatory function. Thus, in patients with total anomalous drainage of the pulmonary veins into the superior vena cava or right atrium, the coexistence of an atrial septal defect is essential to the very maintenance of life, since the only entrance of blood into the left atrium is through the septal defect.

In congenital pulmonic stenosis the right-to-left shunt through a patent foramen ovale or an interatrial septal defect may partially protect the right ventricle from overwork, exhaustion, and final failure.

In any such instance, surgical intervention should be undertaken only with the greatest consideration of the logical consequences. Frequently, unless the primary or coexisting pathology can be simultaneously corrected, surgical closure of the septal defect must be withheld. Fortunately, it is usually possible to correct coexisting mitral stenosis, pulmonic stenosis, and anomalous drainage of the pulmonary veins either simultaneously or at a previous operation. After the surgical correction of a congenital pulmonic stenosis, the right-to-left shunt is usually completely abolished, especially when the interatrial communication is through a patent foramen ovale, as it usually is.

Having satisfied the conditions of preserving any possible compensatory function of the atrial defect and of correcting of any coexisting pathology, the problem of surgically obliterating the defect may remain.

Having simplified the anatomic problem to one of simple deficiency of existing cardiovascular (septal) tissue, the obvious simplified need is to obtain excess cardiovascular tissue from elsewhere which can be applied to neutralize or overcome this deficiency. Some have employed substitute autogenous tissue (Schumacker¹³ and Merendino⁷) or prosthetics (Hufnagel⁸ and Gross⁹) in an attempt to meet this need. Others have used the invaginated right auricular appendage (Cohn⁴) or both appendages (Swan^{5, 6}) to supply the deficiency. These latter efforts have suggested a more logical method of supplying the frequently very large deficiency.

The nearly always greatly dilated outer right atrial wall would seem to offer an ideal and adequate supply of available excess cardiovascular tissue. It is readily applicable to the septum by simple invagination with maintenance of adequate passages for the blood to travel from the respective venae cavae to the tricuspid valve. Accurate hemostatic suturing of the invaginated atrial wall to the edges of the defect is feasible using intracardiac digital guidance for proper placement of the sutures. The right atrial appendage offers an excellent pathway for the intracardiac insertion of the left index finger. The approach to the tricuspid valve is not seriously diminished by such right auricular invagination even in cases of large persistent ostium primum. With care, even in these latter difficult cases, there need be no significant distortion of either the tricuspid or mitral valve leaflets.

Shafiroff and his co-workers¹⁴ have shown that even free grafts of atrial wall readily survive transplantation to various portions of the surface of the

The most severe specifically atrial septal deficiency is the complete absence of the interatrial septum so that there is anatomically a single atrium. This condition implies a complete failure of development of both the septum primum and the septum secundum. It is very rare. Most cases of so-called "single atrium" are cases in which a very large atrial defect exists, permitting free admixture of the atrial contents. Such a case may be considered functionally as a case of "single atrium," but small ridges or remnants of septal tissue indicate that anatomically complete failure of development of one or both of the primitive septa did not occur. In such a case, as in any case with a very large defect, lacelike or ropelike strands of residual septal tissue may bridge the defect. (Fig. 10.)

It is now our belief that by a combination of the techniques of anterior-posterior atrial wall approximation (Murray) and of atrio-septo-pexy that even in cases of single atrium the two atria can be rendered anatomically separate with consequent complete separation of the two circulations. M. K. represents such a condition surgically corrected.



Fig. 11—A, Persistent ostium primum showing lack of a ridge of residual septal tissue. B, Coexistence of true atrial defect and persistent ostium primum. They may join forming a very large combined defect.

The next most serious interatrial communication is the so-called "persistent ostium primum." It represents a failure of normal development of the septum primum. The septal opening is low, extending to the atrioventricular valves which may or may not be deformed. The outline of the defect is usually either roughly crescentic or semicircular with the interventricular septum forming the lower straight margin of the defect. (Fig. 11, A.) In some cases there may be a coexisting defect in the septum secundum either presented as an entirely separate opening, or perhaps joined with the ostium primum. (Fig. 11, B.)

and deliberately with close observance of the electrocardiographic (direct) tracing and of the gross cardiac action. Any irregularity or abnormality suggesting beginning compression or distortion of the conduction system contraindicates further tightening of that suture, and probably should require its immediate removal.

By observance of these two precautions, interference with the cardiac conduction system should be negligible.

PATHOLOGIC ANATOMY

Since interatrial communications are nearly always of congenital origin (except when of traumatic or surgical origin) they follow certain clear-cut patterns depending upon the type of deficiency in embryonic development. It is not the purpose of this article to undertake any detailed description of the embryologic development of the heart or septum. In a previous presentation¹ much of this has been outlined. For more profound consideration of the septal development, the reader is referred to the several excellent available texts on embryology.



Fig 10—Lacelike or netlike strands of tissue may bridge an atrial septal defect.

The most extreme cardiac malformation in which an interatrial communication is prominent is called *atrioventricularis communis*.¹ Here not only the lower atrial septum but also the upper ventricular septum is defective so that all four cardiac chambers are in free communication in the region of the atrioventricular valves. At the present time we are unable to visualize any practical method of performing corrective surgery for this condition.

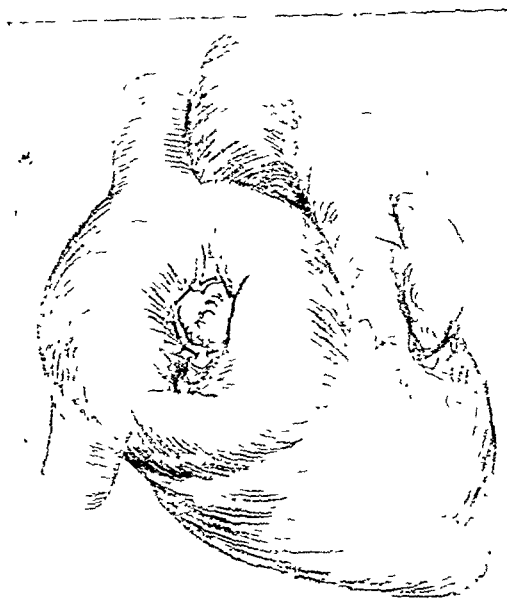


Fig. 13.—Large dimple produced by atrio-septo-pxy in redundant right atrium, converting atrial chamber into doughnut shape.

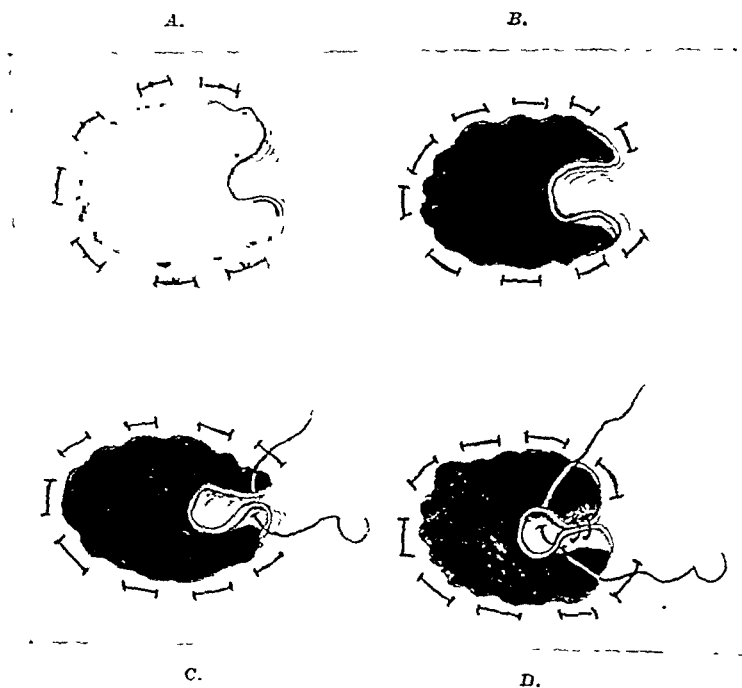


Fig. 14.—A, B, C, and D, Method of closure of very deep lower edge of atrial septal defect by progressive application of deep approximating sutures.

While we originally felt that defects of this type could not be completely closed surgically, by the addition of one or more sutures employing Murray's³ principle, atrio-septo-pxy has proved a very satisfactory and completely effective surgical method.

The central defect of the atrial septum is the commonest type of atrial communication. It is due to improper development of the septum secundum. It may be large or small, but the small defects are seldom recognized during life because they permit only a small shunt and hence few clinical symptoms. The central defect may approach, overlap, or include the foramen ovale but, unlike the latter, does not have a valve on the left side of the opening. Therefore, the resulting shunt may be in either direction or even biphasic.

The central defect is the easiest of all to close surgically. The small ones may be simply sutured together. While Gross^{9, 10} is content with simple closure of such defects, we feel that it is preferable to invaginate and to attach the redundant right atrial wall to the closed defect for reinforcement of the suture line. (Fig. 12, A and B.)

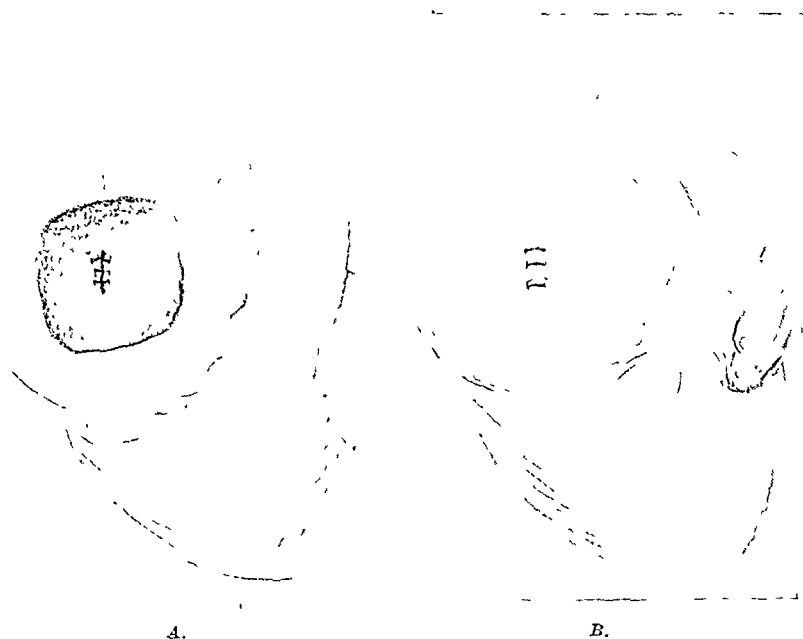


Fig. 12.—A, Direct suture closure of a small atrial septal defect (Gross). B, Invagination and suturing of right atrial wall to reinforce simple suture line of closed atrial defect.

The larger central defect is also usually easily closed by atrio-septo-pxy with an adequate passage for the superior vena caval blood flow being preserved posteriorly. A large (anterior and cephalad) portion of the dilated right atrial wall, including the auricular appendage, is invaginated and sutured to the edges of the septal defect, producing a large eccentric "dimple" in the atrium. (Fig. 13.) Occasionally the larger defects extend so low toward the auriculoventricular valves that they present certain of the surgical

of especial interest because of its frequency (seven in twenty-one operated cases). Since it is partially or completely compensatory, it should not be closed until provision has been made for preservation of a subsequent adequate type of circulation.

Fortunately, in the majority of cases, only part or all of the veins of the right lung enter the right atrium and/or the superior vena cava. In such cases the anomalous veins can be, in effect, transposed into the left atrium by the same maneuvers which close the defect. This technique has been described by Neptune, Bailey, and Goldberg.¹⁵ For the sake of simplification it is possible to consider that the portion of the atrial wall which contains the entrance of the anomalous veins is the portion invaginated and sutured to the edge of

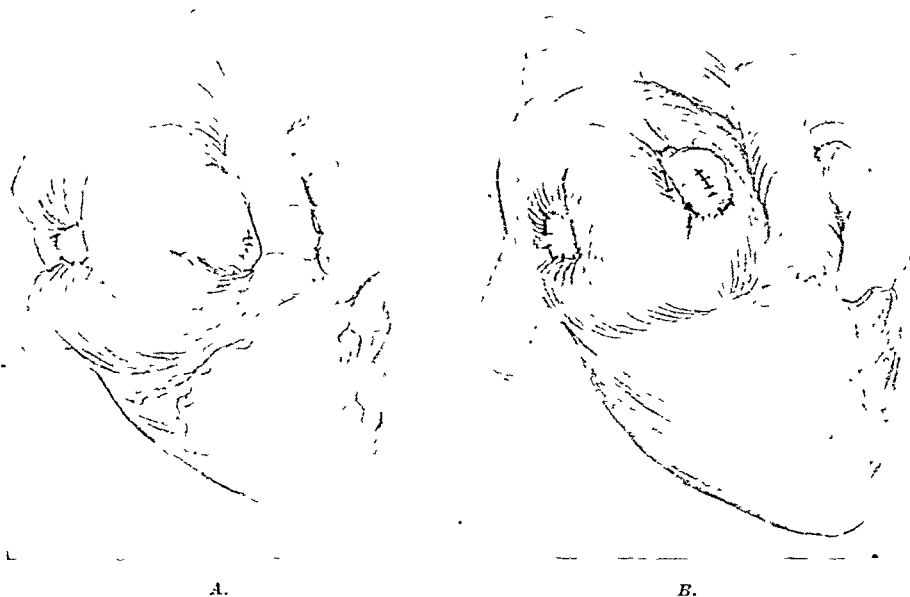


FIG. 16.—A, Rerouting of superior vena caval flow forward by closure of posterior defect. B, Rerouting superior vena caval flow between two areas of invaginating suture repair of small atrial defects.

the defect. The location of the defect (posteriorly) which is uniformly close to the entrance of the vein orifices, probably satisfying certain embryonic relations or requirements, renders such a direct application of the mouths of the vessels into the defect simple and feasible. In actual practice, especially when one or more of the veins actually enters the superior vena cava, it is technically simpler to suture the redundant right atrial wall to the anterior edge of the defect in such a way that the atrium is divided into two compartments. The posterior smaller compartment is excluded from the rest of the right atrium and contains the septal defect and the entrance of the anomalous veins. The stream of the superior vena cava is separated from the anomalous pulmonary venous flow by a row of dividing mattress sutures and is directed

problems usually associated with persistent ostium primum. While there is, in these cases, always a ridge of septal tissue extending up from the valve level, it may be fragile or even lacelike in character. It is also deeply located within the dilated right atrium. Secure suturing of the atrial wall to this ridge then becomes difficult, and if the septal remnant is fragile suturing may be impossible. While sufficient diminution in the size of the defect and hence in the amount of shunt may be attainable for clinical amelioration without complete surgical closure of the defect, such incomplete procedures are obviously undesirable.

The beginner may be content merely to reduce progressively this residual lower portion of the defect by additional mattress sutures which progressively approximate the points of attachment of the invaginated wall to the septum. (Fig. 14, A, B, C, and D.) The more experienced operator will prefer to place one or more anteroposterior approximating sutures after the method of Murray.³ These will effectively close the lower portion of the defect and will complete the correction. The intracardiac digital control of the placement of these sutures makes this portion of the procedure very satisfactory. (Fig. 15.)

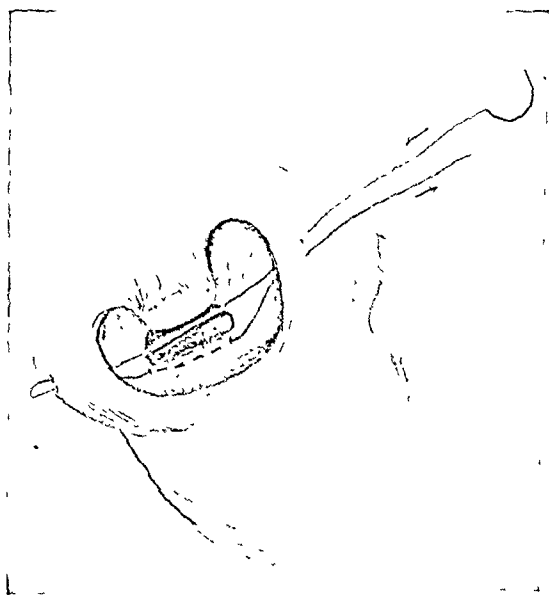


Fig. 15.—Application of one or more anterior-posterior approximating mattress sutures after the method of Murray to close lower margin of persistent ostium primum.

Eccentrically located septal defects and multiple defects provide no special hazards or difficulties (except the possibility of overlooking and therefore of failing to correct the additional lesion). In certain cases they will cause the surgeon to re-route the superior vena caval flow anteriorly or between two areas of approximation of the atrial wall to the septum. (Fig. 16, A and B.)

The interatrial communication associated with anomalous entrance of the pulmonary veins into the right atrium or into the superior vena cava is one

or preferably to the true left atrial chamber at its base. At the same time, any communication to the coronary sinus or to any systemic veins must be interrupted. (Fig. 20, A.)

Fig. 18, A.

Fig. 18, B.

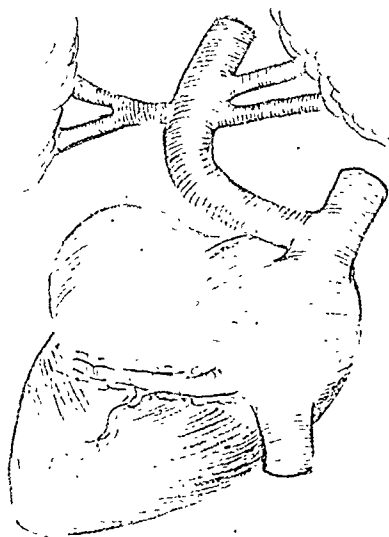
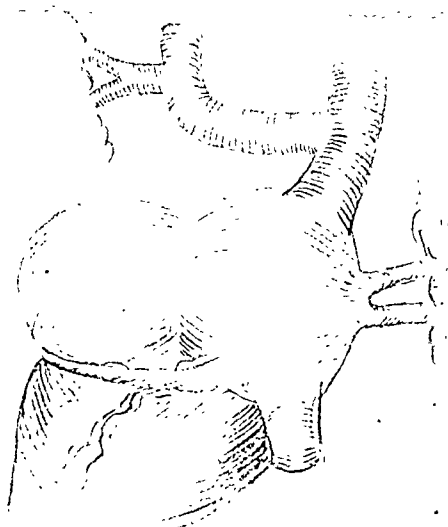
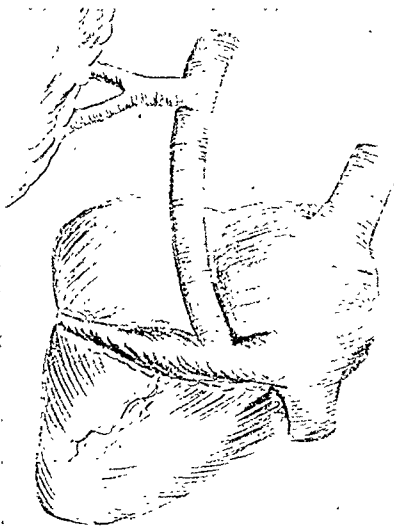
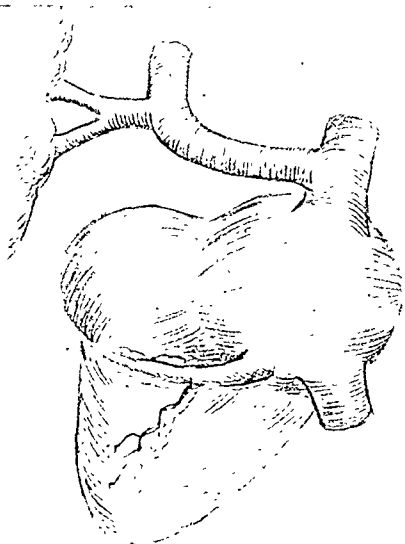


Fig. 19, A.

Fig. 19, B.

Fig. 18.—Left pulmonary drainage into a left superior vena cava which (A) may join the right vena cava or (B) may empty into the coronary sinus (posterior view).

Fig. 19.—In total anomalous venous drainage the right pulmonary veins may empty separately into (A) the right superior vena cava or right atrium or (B) may join the left superior vena cava (posterior view).

forward into the anterior and larger right atrial compartment. This compartment also drains the inferior vena cava and empties into the tricuspid valve. (Fig. 17, *A* and *B*.)

While the exact anatomic details vary in such cases, there is usually a left (as well as right) superior vena cava. The left pulmonary veins drain into a common venous trunk which joins the left superior vena cava. The latter may cross behind the great arterial vessels to empty into the right superior vena cava, or it may drain directly into the coronary sinus. (Fig. 18, *A* and *B*.)

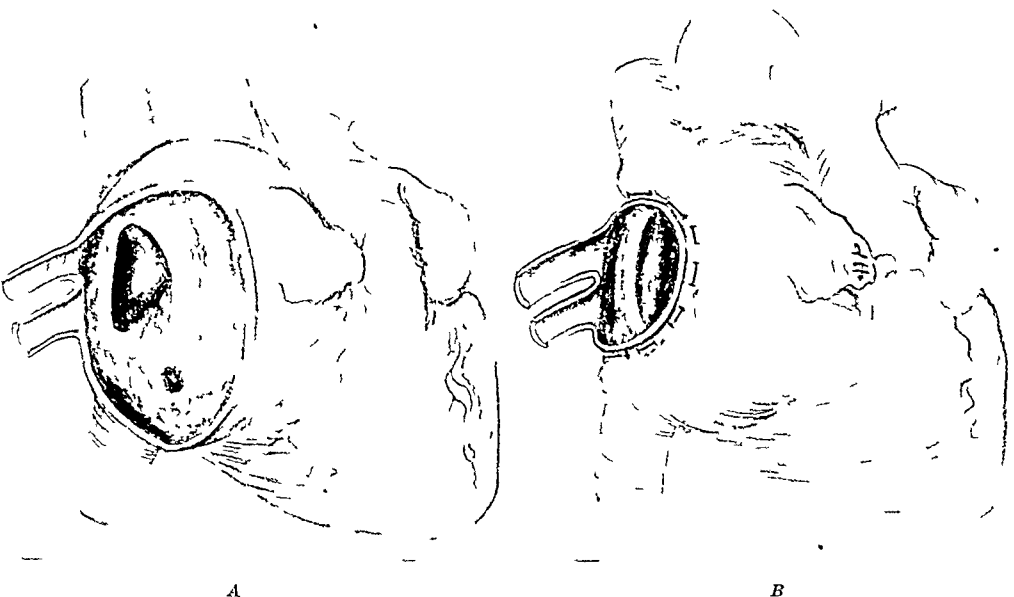


Fig 17—*A*, Anatomic nearness of atrial defect to mouths of anomalous right pulmonary veins suggests a developmental explanation. *B*, By a row of sutures applied as to approximate the septum and the outer wall of the right atrium, the latter is subdivided into two compartments: (1) a small posterior one into which the anomalous veins drain and communicate with the left atrium through the septal defect, and (2) a large anterior one communicating the venae cavae and coronary sinus with the tricuspid valve. This completely separates the two circulations.

When the pulmonary venous drainage of both lungs empties into the right atrium and/or superior vena cava, a two-stage procedure is usually necessary. The exact surgical details depend upon the particular anatomic variant to be dealt with. Since the atrial defect in these cases offers the only possible mode of ingress of blood into the left atrium, it must not be closed until part or all of the pulmonary venous return can enter the left atrium by another route.

The right pulmonary veins may empty directly into the right atrium, and/or the right superior vena cava, or (as in a case recently seen) the left superior vena cava before it joins the right. (Fig. 19, *A* and *B*.)

In any event, the first logical surgical step for the correction of such a combination is an operation of the Muller type¹⁶ upon the left, in which the left pulmonary venous trunk is anastomosed either to the left atrial appendage

or preferably to the true left atrial chamber at its base. At the same time, any communication to the coronary sinus or to any systemic veins must be interrupted. (Fig. 20, A.)

Fig. 18, A.

Fig. 18, B.

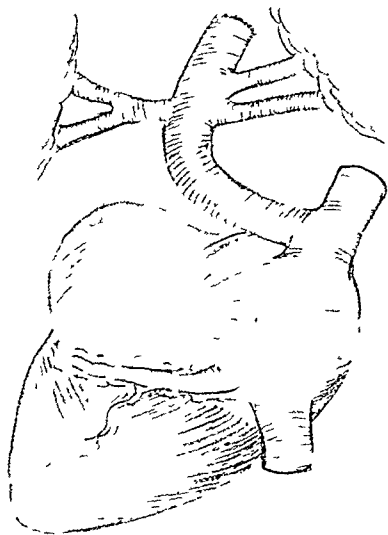
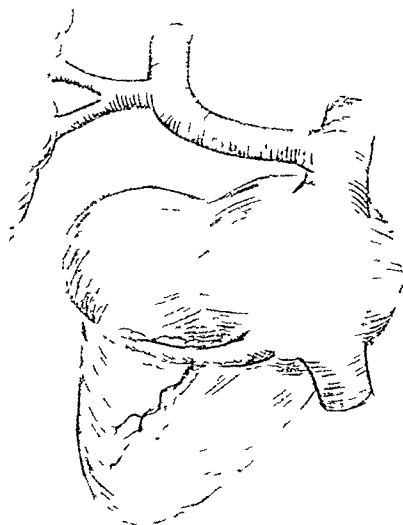


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Fig. 19.—In total anomalous venous drainage the right pulmonary veins may empty separately into (A) the right superior vena cava or right atrium or (B) may join the left superior vena cava (posterior view).

At a second operation, by a right-sided approach, the septal defect is closed and the right pulmonary drainage is transposed into the left atrium by the method of modified atrio-septo-pexy previously described. (Fig. 20, *B*.) However, in the case mentioned, since the right pulmonary veins were already in communication with the left veins via a portion of the left superior vena cava, it would only have been necessary to separate the communication to the right superior vena cava to permit all pulmonary veins to enter the left atrium via the stump of the left auricular appendage. The septal defect could then be closed in the usual manner at a subsequent procedure. (Fig. 21, *A*, *B*, and *C*.)

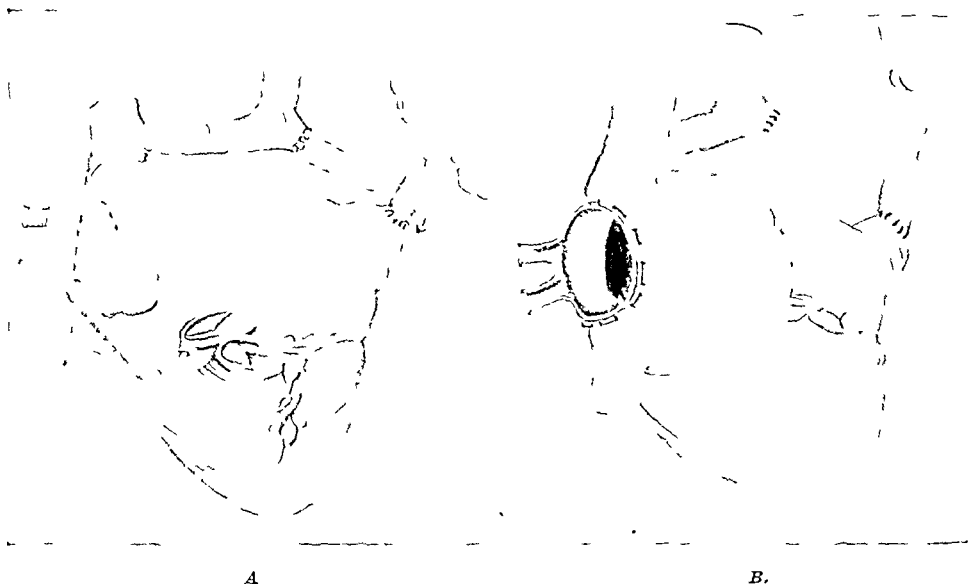
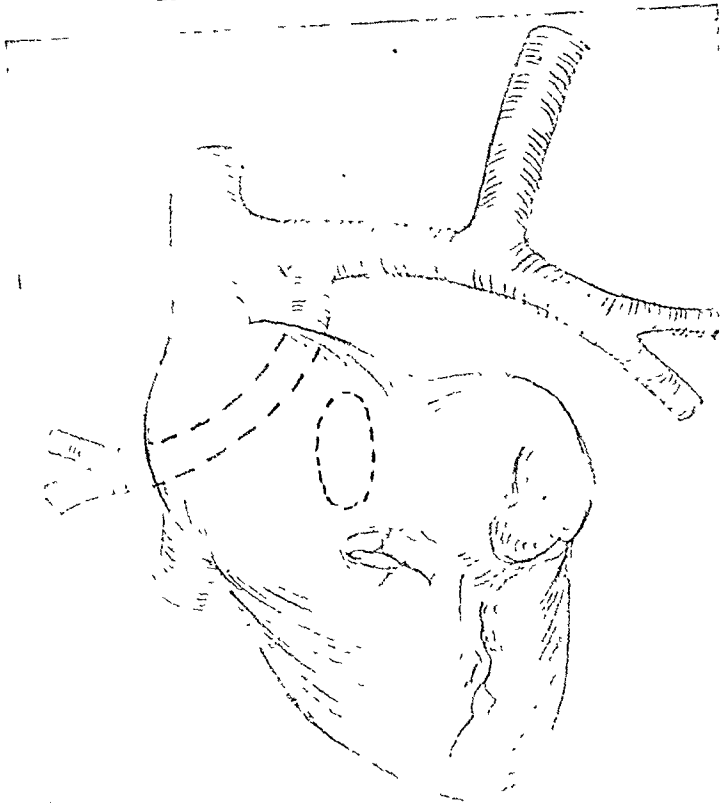
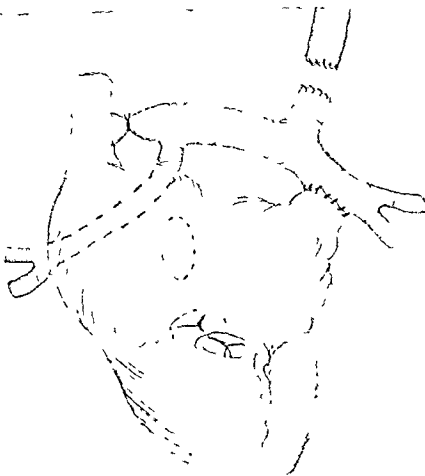


Fig. 20—*A*, The first stage of correction of total anomalous venous drainage is anastomosis of the left pulmonary venous trunk to the left atrium. *B*, The second stage is the transposition of the right venous drainage by modified atrio-septo-pexy.

For the sake of completeness, a persistent patent foramen ovale must be considered among the interatrial communications. Since the foramenal valve is nearly always present and competent, any existing shunt must always be from right to left. A persistent foramen ovale is therefore only functional as a transatrial communication when the pressure in the right atrium is higher than the pressure in the left atrium. The usual clinical condition in which this situation exists is isolated congenital pulmonic stenosis. Such patients frequently show cyanosis or oxygen undersaturation of the peripheral arterial blood because of the passage of unoxygenated blood from the right atrium into the left through the persistent patent foramen ovale. Adequate relief of the pulmonic obstruction by direct surgical attack permits the right atrial pressure to decrease. When it becomes less than that in the left, the foramenal valve closes abolishing further shunt. In such cases, it is apparently unnecessary to attack the foramen itself.



A.



B.



C.

Fig. 21.—A and B, When the veins from both lungs join the left superior vena cava, the first step is a lateral anastomosis of the left venous trunk to the side of the left atrium. The second step is the separation of the pulmonary venous flow from the systemic veins. C, At a second stage the septal defect is closed by atrio-septo-pexy.

Lutembacher syndrome,² by definition, consists of mitral stenosis plus an interatrial communication. Taussig¹⁸ considers that the existence of an interatrial communication predisposes to the development of rheumatic infection and hence of rheumatic mitral stenosis. On the other hand, Lutembacher^{2, 17} felt that the great dilatation of the left atrium which sometimes occurs in mitral stenosis resulted in extreme enlargement of the foramen ovale and in incompetence due to distortion of the foramenal valve so that a left-to-right shunt could occur.

The experience of the senior author (C. P. B.), comprising operative intervention in four cases of Lutembacher syndrome, would tend to uphold Taussig's opinion since a true atrial defect was present in each instance.

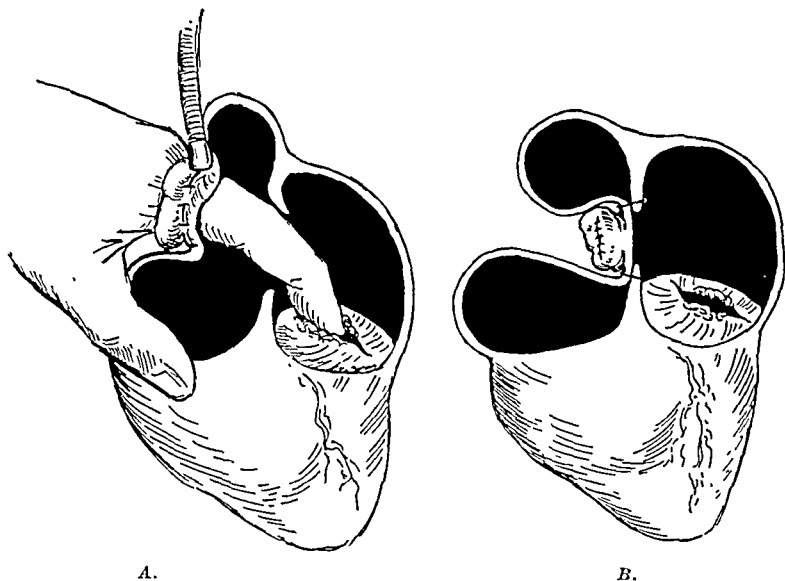


Fig. 22.—A, Performance of digital mitral commissurotomy via right atrial appendage and the septal defect. Incisional commissurotomy may be similarly accomplished. B, Closure of septal defect to complete cure in Lutembacher syndrome.

However, it is evident that regardless of the type of interatrial communication in a case of Lutembacher syndrome, complete surgical correction of the condition requires both relief of the mitral stenosis by adequate commissurotomy and subsequent closure of the defect. In one of the two cases of Lutembacher syndrome detailed herein, a previously unrecognized septal defect was found during the course of a mitral commissurotomy. After completion of this procedure the left thoracic wound was immediately closed and entrance was made through the right chest for a simple atrio-septo-pexy. In the other case, an accurate preoperative diagnosis permitted primary entrance through the right thorax. The mitral valve was approached via the right auricular appendage and the septal defect. A digital commissurotomy was performed with the left index finger, both commissures being split to produce a mitral orifice capable of passing two fingers into the left ventricle. The large defect was then closed in the usual manner by atrio-septo-pexy. Had

instrumental commissurotomy been necessary, no particular difficulty in incising the valve would have been experienced because of this unusual approach. (Fig. 22, A and B.)

If, for some reason, it should be necessary to close a persistent patent foramen ovale, atrio-septo-peny would offer an ideal and simple method.

CLINICAL COURSE AND PROGNOSIS

Abbott¹⁹ states that uncomplicated auricular septal defects, even when of very large size, usually run their course without symptoms until later middle life when these patients commonly die with the appearance of a terminal cyanosis and signs of right ventricular asystole.

Taussig¹⁸ states that patients with interatrial septal defects usually have little trouble in childhood and early adult life but experience great progressive cardiac enlargement and gradual loss of myocardial reserve until congestive heart failure supervenes. She estimates the average length of life in such patients at about 40 years. Bailey, Downing, and their associates¹ have pointed out that there is a great variation in the clinical course and in the life expectancy in various individuals with interatrial communications. Some die in early infancy, while others live to an apparently normal life span without unusual difficulty.

Undoubtedly the course depends largely upon the magnitude of the actual shunt and upon the intrinsic vigor and vitality of the heart muscle. However, associated and intercurrent conditions such as the presence of mitral stenosis, or the development of pulmonary hypertension (evidence of increase in pulmonary vascular resistance) are undoubtedly determinative of the clinical features in many instances.

Probably the most important single pertinent feature is the size of the defect since it does much to determine the size of the flow or shunt between the atria. Undoubtedly, most persons with a large atrial septal defect will show signs and symptoms of loss of cardiac reserve relatively early in life. This is not surprising when we consider that in such cases the pulmonary blood flow is frequently several times that of the peripheral. Such inefficiency of the heart as a pump leads to great and persistent overwork with consequent sharp drop in the usual great myocardial reserve.

Fortunately it is now possible to diagnose accurately nearly every case of significant interatrial communication by catheterization. The only source of frequently unavoidable error is the presence or coexistence of anomalous pulmonary venous drainage. However, since this condition produces a left-to-right shunt very similar to that seen in uncomplicated atrial septal defects, it equally needs surgical correction. It is nearly always associated with a co-existing interatrial communication. Since the required surgery is, in most cases, of a very similar nature (except where actual lobectomy is contemplated) the exact differentiation between these conditions is more of didactic than of clinical importance.

It must be emphasized that no presently existing method of study, including cardiac catheterization, is capable of accurately diagnosing the type

and size of the interatrial septal defect. Fortunately, practically all such defects are readily amenable to corrective surgery. Therefore, exploratory surgery may always be considered as necessary in cases of evident septal defect.

TECHNIQUE OF ATRIO-SEPTO-PEXY

Let us first discuss atrio-septo-pexy in its most simplified and classical form: for a central defect of the septum secundum. With the patient in the supine position, a transverse incision is made over the right anterior thorax to permit wide exposure of the right fourth interspace. Bleeding points are clamped and ligated or coagulated. The fourth interspace is widely opened with division of the fourth and fifth cartilages at the sternum. The internal mammary vessels are divided between clamps and are ligated.

The right lung is compressed and the pericardium is widely opened parallel to, and 1 cm. anterior to, the right phrenic nerve. The anterior lip of the pericardium is suspended anteriorly by traction sutures.

The greatly distended right atrium is then visualized and palpated. An attempt is made to establish the existence or absence of anomalous pulmonary veins which may drain to the superior vena cava or directly into the right atrium. The aortic arch and the pulmonary artery are inspected for hypoplasia, dilatation, and abnormal pulsations or thrills.

A purse-string suture of No. 2 braided silk on a curved atraumatic needle is applied about the right atrial appendage. The ends of the purse-string suture are incorporated within a Rumel-Belmont tourniquet for ease of hemostasis during subsequent intracardiac digital manipulations.

A noncrushing clamp of the Satinsky portacaval or the Potts curved ductus type is placed across the base of the right auricular appendage. A 2 cm. incision is then made into the lumen at the tip, and all obstructing trabeculae are carefully divided. An assistant picks up each lip of the appendageal incision and after flushing with saline, the ungloved left index finger of the operator is inserted into the incision. As the clamp is removed from the appendage the bare finger tip is readily inserted deeply into the arterial chamber.

Exploration is carried out methodically. The superior and inferior venae cavae are first located, and then an attempt is made to feel the ostium of the coronary sinus. The tricuspid valve is located anteriorly and the exploring finger is tentatively passed through it into the right ventricle to corroborate its identity and to estimate the size of its aperture. Any incompetence or stenosis of this valve is noted.

Then a search is made for the septal defect, starting in the region just above (cephalad to) the tricuspid valve. Particular effort is made to determine whether there is a ridge of septal tissue above the auriculoventricular valve or whether it is completely lacking (indicative of a persistent ostium primum). The finger sweeps around the periphery of the defect to determine its size, its shape, the presence or absence of trabeculae, the nature and extent of the tissue making up the edges or remnants of the septum, multiplicity of defects, etc.

After generally exploring the defect, the finger is passed along the posterior (vertebral) margin of the defect and the mouths of the pulmonary veins are located as being either to the left (normal) or to the right (anomalous) of the posterior septal remnant.

Finally the finger tip is passed well through the defect to palpate the left auricular appendage and then posteriorly and inferiorly (caudad) into the mitral valve. Any regurgitation or stenosis is identified, and its degree. If appreciable mitral stenosis exists it must be corrected by digital or digitally guided instrumentation via the atrial defect. All of the usual rules of mitral commissurotomy (Bailey, Bolton, and Redondo-Ramirez²⁰) must be observed, especially with regard to the dangers of production of serious regurgitation.

The line of suturing of atrial wall to septum is now planned. Provision is made for preservation of an adequate intra-auricular passageway for the flow of the superior vena caval blood to the tricuspid valve. In central defects the passageway is preserved posteriorly and the first sutures placed are to the posterior edge of the septal defect routing the vena caval flow behind it. In cases with anomalous drainage of the right pulmonary veins, the first sutures are placed in the anterior edge of the septal defect and the superior vena caval flow is re-routed anteriorly.

The actual atrio-septo-pexy is then begun. The finger is drawn out until only the terminal phalanx remains within the heart. A heavy silk or cotton suture on an atraumatic curved needle (similar to that used for the purse string of the appendage) is passed from the lateral atrial wall near the entrance of the superior vena cava into the lumen of the right atrium, and then into the edge of the septal remnant in this area. The tip of the curved needle is then caused to turn back on itself repuncturing the septal remnant (to produce a mattress suture effect) and to emerge from the lateral atrial wall at a little distance from its entrance. An assistant grasps it and draws the needle from the heart in a turning or rotary fashion. The suture ends are then tied down with considerable tension in order to traumatize somewhat the included auricular wall and septal tissue so that secure approximation and healing will result. It is considered best to interrupt each mattress suture. (Fig. 23, A, B, C, and D.)

Each subsequent suture is applied in overlapping fashion so that one-half of the septal and atrial wall approximated by the previous suture is included in each subsequent one. Thus the line of atrio-septo-pexy would seem to be ensured as anatomically intact. Usually the mattress sutures are applied parallel to the edge of the septal defect. This eventually results in a considerable reduction in the size of the defect by a purse-string-like action. However, individual mattress sutures may be applied at right angles to this line. We do not feel the need of a double line of approximating sutures and fear that it might reduce the residual right atrial chamber unduly.

The redundant right atrial wall is rather readily approximated to the septal edge in the upper portion of the atrium (near the superior vena cava) in all cases. In the case with anomalous right pulmonary venous drainage this ease of approximation to the septal edge is general in all portions of the

suture line. However, in low-placed, large, central defects it may be difficult to approximate the right atrial wall to the lower (caudad) septal margin. An extra large curved needle renders the application of sutures in this area much easier. It is always preferable to have actual atrial wall-septal contact by adequate atrial invagination before attempting to pass the suturing needle.

When the lower margin of the defect is very deep, simple direct suturing to the right atrial wall can be accomplished by using a rather large curved needle. However, this necessarily encompasses a large part of the redundant atrium so that it is excessively used up by such large suture bites. However, if the operator applies this large needle as described, he may merely pass it

A.

B.



C.

D.

Fig. 23.—A, Digital exploration of septal defect via right atrial appendage. B, Placement of first suture in atrio-septo-pexy. C, Progressive approximation of invaginated right atrial wall to periphery of septal defect. D, Completion of atrio-septo-pexy.

until it becomes completely disengaged from the septum but does not completely emerge from the right atrial chamber. The needle holder then grasps the emerging point of the needle and "backs it up," redirecting it so that

Fig 24



Fig 25

Fig 26

Fig 24—Separation of flow of vena caval blood from that of anomalous superior pulmonary vein by a row of mattress sutures

Fig 25—Complete separation of superior vena caval and anomalous pulmonary flow by division and suture

Fig. 26—Continued separation of systemic and anomalous pulmonary venous flow

the "heel" of the needle emerges in reverse fashion from a selected site on the atrial wall about 1 cm. from the original site of entrance. The needle is completely removed from the heart in this retrograde fashion. When this suture is tied down, only a limited portion of right atrial wall will be sacrificed. The extra needle puncture hole will usually not even require a stitch.

In cases with anomalous pulmonary venous drainage where one or more pulmonary veins actually enters the superior vena cava, it is necessary at least to divide the vena caval channel by a row of mattress sutures. (Fig. 24.) Probably it is preferable actually to divide it anatomically between two Potts toothed clamps of the ductus type. The vascular continuity can then be re-established by fine continuous silk sutures. (Fig. 25.) The line of vena caval division is subsequently made continuous with the line of suturing of atrium to the anterior septal edge. (Fig. 26.)

In all cases with anomalous venous drainage the uppermost and lowermost sutures should be placed before the central ones, lest prior application of the central ones interfere technically with the secure application of the less accessible ones at the extremities of the suture line.

In patients with low central defects, great care should be taken to preserve sufficient of the redundant right atrial wall while completing the upper (cephalad) portion of the defect closure to permit the extensive atrial invagination needed in the lower portion. In certain cases it may be necessary to use one or more anterior-posterior approximating mattress sutures employing Murray's principle. The intracardiac finger guides a large slightly curved needle from the upper (anterior) portion of the atrium to, into, and through the lower septal remnant. The needle point traverses the anterior-posterior extent of this remnant and emerges from the posterior atrial wall. It is drawn through and then is passed back in mattress suture fashion, this time crossing the atrial chamber without penetrating the lower septal remnant, emerging close to its point of entrance. Tight tying down of this suture brings about anterior-posterior approximation of the atrial wall in this area and largely completes the closure of the lower portion of the defect. One or more such parallel sutures will usually complete the atrial separation. (Refer to Fig. 15.)

A very similar technique may be applied in cases of persistent ostium primum, but here the suture actually traverses the substance of the uppermost extremity of the interventricular septum (median raphe between the two auriculoventricular valves).

While this modification of the standard technique of atrio-septo-pxy would seem preferable in cases of persistent ostium primum, an alternative method is provided by using an additional left auricular approach for the guiding left index finger. This technique was used in the patient M. G. and permitted complete closure of the lower margin of a persistent ostium primum by simple atrio-septo-pxy without using Murray's principle. (Fig. 27.)

The low anatomic location of the left atrial appendage makes digital guidance of the suturing of the lower margin of an auricular defect, by this approach, much easier than by the usual right approach. However, this

method requires transection of the sternum and opening of both pleural cavities. We believe such an extensive thoracic wound to be unduly hard on the patient.

RESULTS IN THIS PRESENTED SERIES

Table II shows the defects of septum secundum, and Table III lists the defects of septum primum (persistent ostium primum).

In a series of fourteen patients presenting a defect of the septum secundum, two patients were found with coexisting mitral stenosis (Lutembacher syndrome), and there were five patients with anomalous entrance of the pulmonary veins into the right atrium and/or the superior vena cava. These associated conditions were simultaneously corrected. The two operative deaths in this series occurred on the operating table. One patient (B. C.) was shown at autopsy to have a complete thrombosis of the left pulmonary artery, suggesting that anoxemia due to right lung collapse may have precipitated the cardiac standstill.

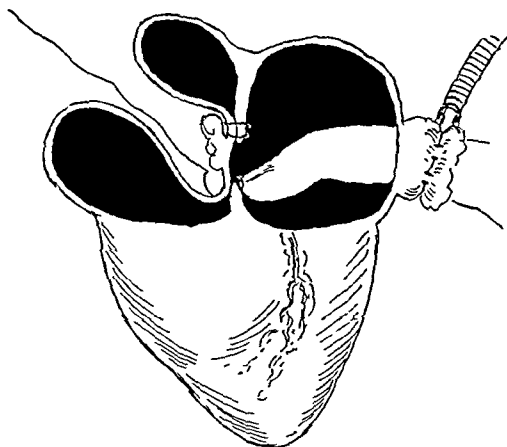


Fig. 27.—Low anatomic position of left atrial appendage renders digital exploration and suture guidance by this route more satisfactory in very low defects such as persistent ostium primum.

The other patient (Y. N.) was in very poor condition preoperatively with an unstable blood pressure.

In seven patients with defects of the septum primum, complete surgical closure was accomplished in four instances. However, death occurred in three cases. In one patient (I. D.) death was apparently related to depression of myocardial activity due to application of hypothermia as an adjunct to surgery. In one patient (M. G.) a renal shutdown appeared immediately after surgery. The third patient (G. H.) was in very poor condition before and during surgery, presenting a serious type of hypotension throughout. Circulation failed to become adjusted in the postoperative period.

In the surviving patients, postoperative catheterization has been carried out in six instances to date. Four of these studies have revealed complete abolition of the shunt and correction of the defect and associated lesions. In

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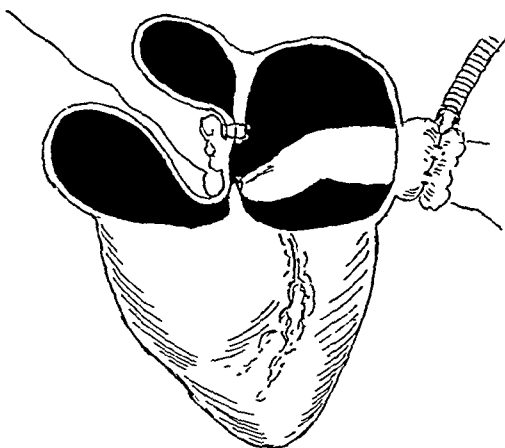


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TABLE II. DEFECTS OF ATRIAL SEPTUM SECUNDUM

CASE NO.	INITIALS	AGE	SEX	OP. DATE	ASSO. VEINUS ANOMALY	LUTEM.	PREOP. CATH.		P.O. CATH.	TRANSP. OF VEINS	CLIN. RESULT
							SHUNT	AMT.			
65121	P. F.	38	W. F.	1/11/52	No	No	L-R	13.2 L./min.	Defect closed	No	Good
73901	M. S.	41	W. F.	8/ 4/52	R. pul. vein entered r. at.	No	L-R	4.3 L./min.	Defect closed	Yes	Good
74855	B. C.	40	W. F.	8/25/52	No	No	L-R	.6 L./min.	None	No	Died
75971	J. S.	11	W. F.	9/19/52	R. pul. vein entered r. at.	No	L-R	26.0 L./min.	Shunt greatly re- duced but not completely	Yes	Good
77508	J. C.	35	W. M.	10/27/52	No	No	L-R	1.8 L./min.	Shunt greatly re- duced but not completely	No	Good
78217	R. B.	44	W. F.	11/10/52	No	Yes	At. defect at surgery	DX	Defect closed	No	Good
81647	T. S.	6	W. M.	1/29/53	R. pul. vein entered r. at.	No	L-R		Defect closed	Yes	Good
	C. M.	8	W. F.	2/12/53	No	No	L-R	6.0 L./min.	None	Yes	Good
	J. R.	31	W. M.	2/13/53	No	Yes	L-R	6.0 L./min.	None	No	Good
	H. N.	39	M.	3/ 5/53	R. inf. pul. v. en- tered r. at.	No	L-R	6.0 L./min.	None	Yes	Good
83452	M. K.	24	W. F.	3/ 6/53	No	No	L-R	13.0 L./min.	None	No	Good
	Y. N.	35	W. F.	3/ 9/53	Sup. p. v. entered sup. vena cava	No	L-R	.135 L./min.	None	Yes	Died
83639	J. B.	22	W. F.	3/16/53	No	No	R-L	.3 L./min.	None	No	Good
83640	C. F.	22	W. M.	3/19/53	No	No	L-R	8.7 L./min.	None	No	Good
							L-R	4.5 L./min.		No	Good

TABLE III. PERSISTENT OSTIUM PRIMUM

CASE NO.	INITIALS	AGE	SEX	OP. DATE	ASSO. VENOUS ANOMALY	LUTEM-BACHER	PROOP. CATHETERIZATION	P.O. CATH.	TRANSP. OF VEINS	CLIN. RESULT
74754	M. S.	44	W. M.	5/22/52	No	No	L-R shunt 2 L./min.	No	No	Good
78294	I. D.	27	W. F.	11/10/52	No	No	L-R shunt 3.3 L./min.	No	No	Died
79415	M. G.	11	W. F.	12/ 8/52	No	No	No	No	No	Died
80193	G. H.	27	W. F.	1/ 5/53	Rt. pul. v. entered rt. atrium	No	L-R shunt .2 L./min.	No	Yes	Died
82658	M. K.	25	W. M.	2/27/53	Rt. pul. v. entered rt. auricle	No	L-R shunt 5.5 L./min.	No	Yes	Good
81126	A. C.	17	W. M.	3/21/53	No	No	L-R shunt	No	No	Good
YYY	F. B.	23	W. M.	3/26/53	No	No	L R shunt	No	No	Good

two, it is evident that a small residual interatrial communication and shunt persists. However, the clinical improvement has been remarkable even in these patients. All evidence of impairment of myocardial reserve has disappeared, and they have returned to full normal activity. Indeed, only one patient in the entire series (M. S.) has failed to make a complete clinical recovery.

CASE REPORTS

CASE 1.—P. F., Hahnemann Hospital, No. 65121, a white woman, 38 years old, was operated on Jan. 11, 1952. A heart murmur had been present from birth. One year prior to admission dyspnea on exertion developed, becoming progressively more incapacitating. Three months before admission, cardiac catheterization was performed at another hospital. The catheter passed through an atrial septal defect and the blood oxygen studies demonstrated a large left-to-right shunt. On physical examination the heart was enlarged. There was no thrill. The pulmonic second sound was markedly accentuated. A rough, Grade 3, systolic murmur was heard in the third left interspace. The electrocardiogram showed marked right ventricular hypertrophy and strain. On fluoroscopy the pulmonary vascular markings were greatly accentuated. The heart was enlarged to right and left. The right auricle and ventricle were very prominent. The left cardiac chambers were of normal size. The main pulmonary artery was hugely dilated, and the right and left pulmonary arteries were very prominent. Pulsations were increased. The aorta appeared relatively small.

At operation on Jan. 11, 1952, the interatrial septal defect was completely obliterated by atrio-septo-pxy. The early postoperative course was marked by much difficulty with regard to retained bronchial secretions. Bronchoscopy was necessary on four successive days. On the second postoperative day auricular fibrillation developed but was readily controlled. On the sixth day a right paravertebral thoracic nerve block, T 3 to T 8 inclusive, was performed because of persistent right chest pain. Throughout the remainder of the hospital stay the patient's condition progressively improved, although there was persistence of râles, bronchial breathing, and dullness at the right base. At no time was there cyanosis or venous distention. No murmur was audible, and there was a significant decrease in the intensity of the pulmonic second sound. Fluoroscopy before discharge showed the pulmonary vasculature to be unchanged, but there was a decrease in the transverse diameter of the heart. Cardiac catheterization indicated that there now was no left-to-right shunt.

CASE 2.—M. S., Hahnemann Hospital, No. 73901, a 41-year-old white woman, was operated on Aug. 4, 1952. The patient had had rheumatic fever at the age of 16 years. Heart murmur was first detected eleven years ago. Subsequent repeated rheumatic episodes followed. Exertional dyspnea, nocturnal dyspnea, and orthopnea were also present, and the patient experienced near-syncope upon descending stairs. Harsh systolic murmur was heard at the apex and along left sternal border. Preoperative cardiac catheterization revealed atrial septal defect, anomalous pulmonary venous drainage into the right atrium or superior vena cava. Atrio-septo-pxy and transposition of anomalous pulmonary veins into the right atrium were performed. Postoperative catheterization revealed the previous left-to-right shunt had been completely eliminated. Patient had a good postoperative course and is asymptomatic.

CASE 3.—B. C., Hahnemann Hospital, No. 74855, a white woman, 40 years old, was operated on Aug. 25, 1952. Heart murmur had been noted 15 years previously. There had been progressive exertional dyspnea for the past year with occasional ankle edema. Preoperative cardiac catheterization revealed an atrial septal defect with anomalous pulmonary venous drainage into the right atrium. Over-all left-to-right shunt, 0.6 L. per minute, was present. Atrio-septo-pxy was performed on Aug. 25, 1952. During the operative procedure, cardiac arrest occurred; the usual supportive measures were not effectual in resuscitating the heart beat, and the patient expired on the operating table.

CASE 4—J S, Hahnemann Hospital, No 75971, an 11 year old white girl, underwent operation on Sept 19, 1952. She was subject to frequent upper respiratory infections and repeated illnesses until the age of 6 years. Murmur was detected during the first year of life. Exercise tolerance was progressively poor. No cyanosis was present, however, she had experienced four episodes of syncope. The heart was enlarged to two plus. There was normal sinus rhythm, but systolic murmur to the left of the sternal border at the fourth and fifth interspaces. There was a midlate diastolic murmur in same area. Preoperative cardiac catheterization revealed atrial septal defect. Atrio septo pévy under hypothermia (88° F) was performed on Sept 19, 1952. An ostium secundum about 2 cm in diameter existed as well as a right pulmonary vein entering into the right auricle. Postoperative catheterization revealed a very small shunt at the atrial level, but it was not significant. It was thought that the tip of the catheter might have been actually through the septum, perhaps between the sutures in the atrial wall. Postoperative course satisfactory. Clinical improvement is excellent.

CASE 5—J C, Hahnemann Hospital, No 77508, a 35 year old white man, was operated on Oct 27, 1952. He had suffered from increasing fatigue and dyspnea for one year. Two episodes of mild cardiac failure had occurred within the past year. Until 10 years ago he had led an active life in sports. Grade 2 systolic murmur was present over the apex. There was reduplication of pulmonic second sound and râles at both bases of the lungs. Markedly enlarged pulmonary artery and enlargement of the left auricle and right ventricle were observed. Preoperative cardiac catheterization revealed interatrial septal defect and severe pulmonary and right ventricular hypertension, left to right shunt was present at the atrial level. Atrio septo pévy was performed and a good postoperative course followed. Postoperative cardiac catheterization on March 20, 1953, revealed that the defect was greatly reduced but not completely closed.

CASE 6—R B, Hahnemann Hospital, No 78217, a white, 44 year old woman, underwent operation on Nov 10, 1952. Cardiac decompensation had first occurred fourteen years ago. It had grown progressively worse during the past year. The patient went to surgery on Nov 10, 1952, with preoperative diagnosis of rheumatic valvular heart disease, inactive, with mitral stenosis, advanced, and mitral insufficiency, minimal. Findings at operation revealed mitral stenosis with an interatrial septal defect and some degree of tricuspid regurgitation. Mitral commissurotomy was performed (both anterior and posterior commissures) as well as atrio septo pévy. The patient had a satisfactory postoperative course. Cardiac catheterization, performed postoperatively, revealed the defect to be closed.

CASE 7—T S, Hahnemann Hospital, No 81647, a 6 year old white boy, was operated on Jan 29, 1953. Murmur had been known to be present since birth. He had frequent respiratory infections, very slight cyanosis of the lips, and limited exercise tolerance. Preoperative cardiac catheterization demonstrated atrial septal defect, physiologically significant, and also suspected anomalous pulmonary venous drainage into the right atrium. On Jan 29, 1953, atrio septo pévy with transposition of the right pulmonary vein into the atrial septal defect was performed. The patient had a very satisfactory postoperative course. One catheterization has been performed postoperatively, but it was unsatisfactory and will have to be repeated. Subsequent cardiac catheterization revealed the defect to be closed.

CASE 8—C M, Hospital São Paulo, Brazil, an 8 year old girl, underwent operation on Feb 12, 1953. She had a history of a murmur at birth, but no cyanosis. She could only engage in limited activity. Preoperative cardiac catheterization revealed a left to right shunt, 6 L per minute. An atrial septal defect was located in the center of the septum, 2 cm in diameter. Atrio septo pévy was performed with invagination of the atrial wall to the edges of the defect. There were no anomalous veins. Postoperative course was satisfactory, and clinically it was markedly improved. No postoperative cardiac catheterization was done.

CASE 9—J R, Samaritan Hospital, São Paulo, Brazil, a 31 year old white man, was operated on Feb 13, 1953. He had Lutembacher syndrome. A murmur had been present

since childhood; there was no cyanosis, but he had experienced marked and progressive physical incapacity and failure for the past two years. Physical examination revealed a sharp first sound, a late diastolic murmur, and a presystolic accentuation over the apical region. A three plus systolic murmur was present over the entire precordium. There was marked cardiac enlargement. Liver was enlarged four fingerbreadths below the costal margin. Preoperative cardiac catheterization revealed a left-to-right shunt of 6 L. per minute. The chest was entered through the right fourth intercostal space. Great dilatation of the right auricle. The septal defect, 3 cm. in diameter, was centrally located but extended to the atrioventricular valve. The mitral valve was severely stenosed and a mitral commissurotomy was performed by digital pressure through the auricular defect as the heart was entered through the right auricle. Atrio-septo-pxy was accomplished with difficulty because of the extreme depth of the lower edge of the defect. Finally, it was accomplished by mattress sutures through the anterior to the posterior atrial wall. Postoperatively there was marked clinical improvement. There has been no postoperative catheterization as yet.

CASE 10.—H. N., Edgewater Hospital, Chicago, a white man, aged 39, was operated on March 5, 1953. The patient showed progressive inability to carry out his work as a welder, but was not totally incapacitated. Preoperative cardiac catheterization revealed a left-to-right shunt of 6 L. per minute. At operation it was found that the right inferior pulmonary vein entered the right auricle. There was an interatrial septal defect of 1.5 cm. located posteriorly and situated close to the anomalous vein orifice. Atrio-septo-pxy was performed and closure of the septal defect accomplished with a diversion of the stream of blood from right inferior pulmonary vein through the defect.

CASE 11.—M. K., Doctors Hospital, a white woman, 24 years old, was operated on March 6, 1953. First knowledge of heart disease was three years ago. Gradually increasing exertional dyspnea and severe palpitation had occurred during the past two years. Preoperative cardiac catheterization revealed a left-to-right shunt of 13.0 L. per minute. Atrio-septo-pxy was performed March 6, 1953. A septal defect approximately 3 cm. in diameter was completely closed. The patient had a very smooth postoperative course. Postoperative cardiac catheterization has not yet been performed.

CASE 12.—Y. N., Hahnemann Hospital, No. 83452, a 35-year-old white woman, underwent operation March 9, 1953. Onset of progressive dyspnea and precordial pain had begun at the age of 17 years. Embolization and right hemiplegia occurred in January, 1953, during cardiac catheterization with recovery. The patient experienced occasional cyanosis, especially in the lower extremities. After cardiac catheterization was performed and mild hemiparesis resulted, the patient was discharged from the hospital, then readmitted. At the time of operation, no sequelae of the hemiplegia existed. Atrio-septo-pxy and reimplantation of superior vena cava into the right auricle were performed. The patient went into cardiac arrest and expired during surgery.

CASE 13.—J. B., Hahnemann Hospital, No. 83639, a 22-year-old white woman, was operated on March 16, 1953. The patient was asymptomatic and worked as a graduate nurse without difficulty. Preoperative cardiac catheterization revealed a left-to-right shunt at the atrial level of 8.7 L. per minute. Diagnosis of the patient's condition was atrial septal defect. Atrio-septo-pxy was performed. The postoperative course was very smooth. No postoperative cardiac catheterization has been performed as yet.

CASE 14.—C. F., Hahnemann Hospital, No. 83640, a white man, 22 years old, underwent operation March 19, 1953. Murmur had been present at birth. He was somewhat dyspneic upon exertion; slight cyanosis of the lips was observed. Grade 2 blowing systolic murmur at the apex, inconsistent at the base, was present. Preoperative cardiac catheterization revealed a 4.5 L. per minute shunt, left-to-right. Atrio-septo-pxy was performed. There were no anomalous pulmonary veins. Postoperative course has been very satisfactory. Postoperative catheterization has not been performed.

CASE 15.—M. S., Hahnemann Hospital, No. 70754, a white man, 44 years old, was operated on May 22, 1952. Murmur was discovered at age of 12 years. He had been asymptomatic until he was 36 years old when an enlarged heart was found. Fatigability, gradually diminishing exercise tolerance with dyspnea, and nocturnal dyspnea were present. Repeated hemoptysis was present. The preoperative cardiac catheterization diagnosis was Lutembacher syndrome. Atrio-septo-pexy was performed and a persistent ostium primum was found. A complete closure was felt to have been obtained. However, there was great tension upon the sutures and the suspicion was that these may ultimately tear and reproduce some minor interatrial communication. Good clinical result has been obtained thus far. No mitral stenosis found at surgery.

CASE 16.—I. D., Hahnemann Hospital, No. 78294, a white woman, 27 years old, underwent operation Nov. 10, 1952. The patient had a history of a murmur present since the age of 5 years. She had been asymptomatic until six weeks ago at which time she experienced paroxysmal tachycardia, weakness, and near collapse. The patient had experienced moderate fatigue for one year. Preoperative catheterization revealed atrial septal defect and possible ventricular septal defect. Operation took place under hypothermia (72° F.). Ventricular fibrillation occurred prior to the entry into the heart; electric shock reverted to normal rhythm. Atrial septal defect closed by the closed technique of atrio-septo-pexy. However, ventricular fibrillation reoccurred and was again converted to a normal sinus rhythm with intermittent cardiac massage and electric shock. Ventricular fibrillation recurred again after patient was removed to the recovery room, and the patient expired.

CASE 17.—M. G., Hahnemann Hospital, No. 79415, an 11-year-old white girl, was operated on Dec. 8, 1952. Questionable episode of cardiac failure had occurred at the age of 7 years. The patient experienced gradually increasing fatigue and decreased exercise tolerance. Cardiac catheterization revealed atrial septal defect, and because of deterioration the patient was referred for surgery. Atrio-septo-pexy was performed. A 5 cm. interatrial defect was closed with the exception of a portion about 0.5 cm. in diameter. Postoperative condition seemed fairly satisfactory until the sudden cessation of respirations and cardiac arrest approximately twenty-six hours after surgery. No autopsy was obtained.

CASE 18.—G. H., Hahnemann Hospital, No. 80193, a white, 27-year-old woman, was operated on Jan. 5, 1953. She had experienced fatigue, nocturnal dyspnea, and congestive failure of five years' duration. There had been one episode of cyanosis. Severe exertional dyspnea, and occasional ankle edema were noted. Blood pressure was 134/106; a gallop rhythm was present. Preoperative cardiac catheterization revealed anomalous pulmonary venous drainage into the right superior vena cava and the right atrium, ventricular septal defect (high), atrial septal defect (?), persistent left superior vena cava, and pulmonary vascular changes. Operation consisted of closure of interatrial septal defect and transposition of anomalous pulmonary veins. The patient died a few hours after surgery with sudden respiratory distress and cardiac standstill. Cardiac massage failed to reinstitute function except for ventricular fibrillation which shortly ceased.

CASE 19.—M. K., Hahnemann Hospital, No. 82658, a 25-year-old, white man, underwent operation Feb. 27, 1953. Cyanotic from birth, the patient experienced gradually increasing dyspnea throughout life; he had never been able to engage in sports. Preoperative cardiac catheterization revealed a left-to-right shunt at the atrial level of 5.5 L. per minute. A diagnosis of atrial septal defect, dynamically significant, and associated anomalous pulmonary veins draining into the right auricle was made. Atrio-septo-pexy was performed with transposition of the right pulmonary vein into the septal defect, thus transposing the drainage into the left auricle. The defect was found to be about 2 inches in diameter and appeared to be persistent ostium primum. The postoperative course was rather stormy with physical findings compatible with some degree of obstruction of the inferior vena cava developing on the eighth postoperative day.

CASE 20.—A. C., Hahnemann Hospital, No. 84126, a white boy, 17 years old, was operated on March 24, 1953. Gradually increasing exertional dyspnea and orthopnea had

been present for five years. He was unable to attend school because of increasing fatigue. Preoperative cardiac catheterization revealed atrial septal defect, with significant left-to-right shunt. Atrio-septo-pxy was performed on March 24, 1953. Postoperative condition is satisfactory.

CASE 21.—D. M., a white man, 21 years old, underwent operation on March 26, 1953, at Samuel Merritt Hospital, Oakland, Calif. The patient experienced fatigue and dyspnea on exertion. He is now a student. Preoperative catheterization revealed a left-to-right shunt. Atrio-septo-pxy was performed for a persistent ostium primum. Transient atrial flutter developed postoperatively. No postoperative catheterization has been performed as yet. Subjectively, the patient is doing well.

SUMMARY

1. Atrio-septo-pxy is a relatively simple, straightforward, surgical plastic procedure capable of closing nearly all types of atrial septal communications by bridging the defect with a portion of the invaginated right auricular wall.

2. No significant interference with the flow of vena caval blood need be produced. The auriculoventricular valves need not be disturbed. Should it ever prove necessary to interrupt completely the superior vena caval flow, this can be tolerated if the azygos vein system is preserved intact.

3. Associated lesions such as coexisting mitral stenosis or anomalous entrance of the right pulmonary veins into the right atrium and/or superior vena cava can and should be readily corrected at the time of closure of the defect.

4. Coexisting total transposition of all pulmonary venous return probably requires a two-stage surgical procedure for its correction.

5. Very low defects such as persistent ostium primum may require the addition of anterior-posterior approximating atrial mattress sutures, after the method of Murray.

6. Great defects such as single atrium may be improved or corrected by a modification of Murray's technique.

7. To date the results obtained in correcting defects of the septum secundum have been reasonably satisfactory. There was operative mortality in fourteen cases of 14.3 per cent, complete anatomic correlation proved in four of six cases studied by catheterization (66.3 per cent), and clinical improvement notable in all of the survivors (100 per cent).

8. In seven cases of persistent ostium primum complete closure of the defect was accomplished in four instances. Deaths occurred in three of the seven patients (43 per cent) apparently as a result of unrelated factors: hypothermic depression of the myocardium, renal shutdown, very poor condition. The surgical measure, itself, should not entail a great mortality.

ADDENDUM

Since the time of submission of this paper, we have operated two additional ostium primums with one death. We have done five additional septum secundums with no fatalities.

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Announcement

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The 34th annual meeting of the American Association for Thoracic Surgery will be held May 3, 4, and 5, 1954, in Montreal, Que., Canada. Headquarters will be at the Sheraton-Mount Royal Hotel.

Requests for Hotel Reservations

These should be mailed *directly* to the Reservation Manager, Sheraton-Mount Royal Hotel, Montreal, Que., Canada. Please mention this Association, type of accommodation desired, date, and approximate hour of arrival. If accommodations are desired elsewhere, please communicate directly with hotel of your choice.

Thoracic Surgical Forum

After due consideration, the Council has decided to try an experiment by assigning one morning session to a "Thoracic Surgical Forum" for the presentation of short papers on current thoracic research, anatomy, modified surgical techniques, etc. Papers at this session will be limited sharply to ten minutes (including the showing of lantern slides or other illustrative material) with three minutes as the maximum discussion of each paper.

These papers will be published together in one issue of THE JOURNAL OF THORACIC SURGERY. Maximum length: 3,000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts for Papers

Abstracts for the presentation of papers at the 1954 meeting, including papers before the Forum, must be received on or before January 1, 1954, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Forum" or "For Regular Program."

Five, repeat five, copies of each abstract should be sent to the Secretary of the Association, Dr. Paul C. Samson, 2938 McClure St., Oakland 9, Calif. They should not be sent to the Editor.

The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Jan. 1, 1954, to be considered for action in Montreal. Applications received beyond this deadline will be deferred for consideration until 1955.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the sponsoring statement on the application form, the sponsors *must* submit a separate letter concerning the applicant direct to Dr. Lyman H. Brewer, III, Chairman of the Membership Committee, 2010 Wilshire Blvd., Los Angeles, Calif. Completed application forms should likewise be sent to Dr. Brewer. These regulations are at the direction of the Council and were made effective in 1952 at Dallas.

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Original Communications

LOCALIZATION OF RADIOACTIVITY IN THE LUNG AND THE LYMPH NODES

J. RAY BRYANT, M.D. (BY INVITATION), HAROLD F. BERG, M.D. (BY INVITATION),
AND WILLIAM M. CHRISTOPHERSEN, M.D. (BY INVITATION)
LOUISVILLE, KY.

THERE appears to have been a real increase in the incidence of lung carcinoma until it now has probably replaced gastric carcinoma as the first cause of death from cancer.¹ In the ten-year period from 1938 to 1948 the number of reported fatalities from bronchiogenic carcinoma in the United States increased 144 per cent.² The only adequate treatment of this type of carcinoma is pneumonectomy with complete removal of the mediastinal lymph nodes. One group was able to perform resection in 35 per cent of all patients seen, but in only 30 per cent of these was the lesion confined to the lung. Of a total series of 948 patients seen, 6 per cent were alive at the end of a five-year period.² The five-year survival rate in treated asymptomatic lung cancer is the only side of the picture to offer much encouragement. There remains a large number of patients with nonoperable lung cancer in which palliation is the only direction that therapy can take. It is with this latter group in mind that this problem was designed.

A method of delivering effective radiation limited to specific segments of the lung and the regional lymph nodes has been attempted. The method used was direct instillation of a radioactive colloid into a segmental bronchus and direct injection of the same solution into the submucosa of the intermediate bronchus.

The colloidal particles are apparently engulfed by phagocytes and carried through the lymphatic channels to the recipient lymph nodes.^{3, 4}

If the radioactive dispersion in the involved segment of lung and the uptake in the regional lymph nodes are high enough to deliver a therapeutic amount of radiation, a certain degree of palliation should be anticipated.

From the Departments of Surgery and Pathology, University of Louisville School of Medicine.

This project was supported by a grant from the Damon Runyon Memorial Fund for Cancer Research.

The work was done under the supervision of Dr. Marshall Brucer, Chairman of the Medical Division of Oak Ridge Institute of Nuclear Studies.

Miss Germaine Click contributed invaluable technical help and advice.

Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 30, 1953.

ISOTOPE

Radioactive colloidal Au^{198} was used. Colloidal Au^{198} may not necessarily be the ideal isotope for clinical application of this method, but it was chosen because of its availability and short half-life which make it a convenient and desirable laboratory isotope. Au^{198} has a half-life of 2.7 days. It emits beta rays with maximum energy of 0.97 MEV and gamma rays with energy of 0.411 MEV.⁵ Fifty per cent of the beta particles penetrate only 0.38 mm. and these particles are the primary source of the radiation effect. The gamma rays penetrate deeply and are useful for external counting. The isotope, obtained from Abbott Research Laboratory of Oak Ridge, Tenn., is a colloidal solution of particle sizes stated to range from .003 to .004 micron.

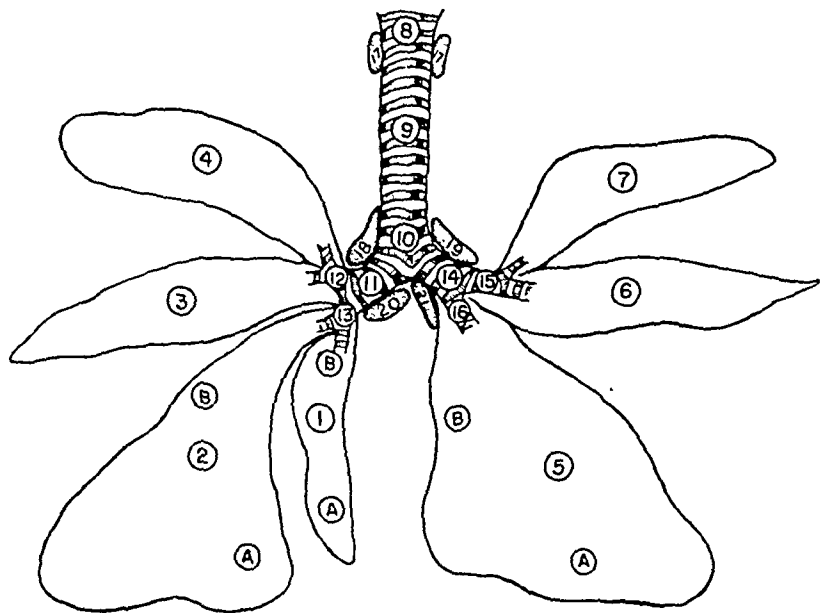


Fig. 1.—Schematic diagram of the lung and regional lymph nodes of dog indicating areas of assay.

METHOD

Apparently healthy mongrel dogs were used. The dogs were anesthetized with intravenous Nembutal, 30 mg. per kilogram of body weight. Two methods were tried.

1. *Instillation*.—Through a bronchoscope, a ureteral catheter was placed in a segmental bronchus. The bronchoscope was then removed, the head of the dog was elevated twelve inches, and the colloidal Au^{198} was injected into the catheter. The catheter was removed. The dog was kept in the same position for several hours to avoid reflux of the solution.

2. *Injection*.—Through a bronchoscope, a long needle (type used for injecting esophageal varices) was placed into the submucosa of the intermediate bronchus. Colloidal Au^{198} was injected through the needle. The site of injection was then re-examined to detect proper delivery.

DOSE

Amounts ranging from 2 to 5 mc. of colloidal Au^{198} in 5 c.c. of normal saline solution were used in the instillation method. In the five dogs that were observed for long-term effects, two dogs received 3 mc. each, one dog 15 mc., one 25 mc., and one 35 mc., all in 5 c.c. volume. In the injection method, 2 mc. in 2 c.c. volume was used.

AUTOPSY AND ASSAY

The dogs were sacrificed at intervals ranging from five to sixty-one days after administration of the isotope. Specimens taken from various organs including lymph nodes (Fig. 1) were measured for radioactive uptake and examined for histologic changes.

The tissues that were studied for uptakes were weighed, digested in nitric acid and diluted to 10 c.c. volume. The activity in this wet sample was measured with an end-window Geiger-Müller tube. All figures are recorded as the counts per minute per gram of fresh tissue, corrected for decay from the time of animal injections.

RESULTS OF ASSAY

1. Instillation Method.—Tables I and II. Twenty dogs were used in this experiment. The results of the assay for radioactivity showed an extremely high concentration in the segment of lung into which the solution had been instilled. High levels were also found in some of the hilar lymph nodes. The longer the survival time, the greater was the number of lymph nodes that were found to have radioactivity. The uptake in other organs and particularly the spleen and liver was very low, indicating that little activity entered the blood stream.⁶ Five dogs were kept for long-term studies and were allowed to survive up to sixty-one days. These dogs were not assayed but were examined for histologic changes.

2. Injection Method.—Table III. Eight dogs were subjected to direct injection of the isotope into the submucosa of the right intermediate bronchus. In these the radioactive concentration in all the hilar lymph nodes was consistently high. The uptake in the lung was minimal. In the one exception (Dog 116) there was undoubtedly some leakage at the time of injection. The levels in the liver, spleen, and other organs were extremely low. The site of injection showed a high level of activity but had a lower concentration than that found in the regional lymph nodes.

PATHOLOGY

The lungs of seven dogs receiving 3 to 5 mc. of colloidal Au^{198} were examined twelve days after instillation of the isotope. The lower lobe segments of the right lung corresponding to the bronchus into which colloidal Au^{198} was placed, were all heavy, red, and nonrepitant. The remainder of the lungs showed no significant changes, either grossly or microscopically. The involved segments were the site of edema, congestion, and atelectasis. The alveolar septa were thickened and the lining cells were swollen; a few cells contained black pigment. There was extensive exudate in the alveolar sacs, composed largely of lymphocytes and monocytes. A single lung (Dog 95) showed fresh necrosis. Many of

ISOTOPE

Radioactive colloidal Au^{198} was used. Colloidal Au^{198} may not necessarily be the ideal isotope for clinical application of this method, but it was chosen because of its availability and short half-life which make it a convenient and desirable laboratory isotope. Au^{198} has a half-life of 2.7 days. It emits beta rays with maximum energy of 0.97 MEV and gamma rays with energy of 0.411 MEV.⁵ Fifty per cent of the beta particles penetrate only 0.38 mm. and these particles are the primary source of the radiation effect. The gamma rays penetrate deeply and are useful for external counting. The isotope, obtained from Abbott Research Laboratory of Oak Ridge, Tenn., is a colloidal solution of particle sizes stated to range from .003 to .004 micron.

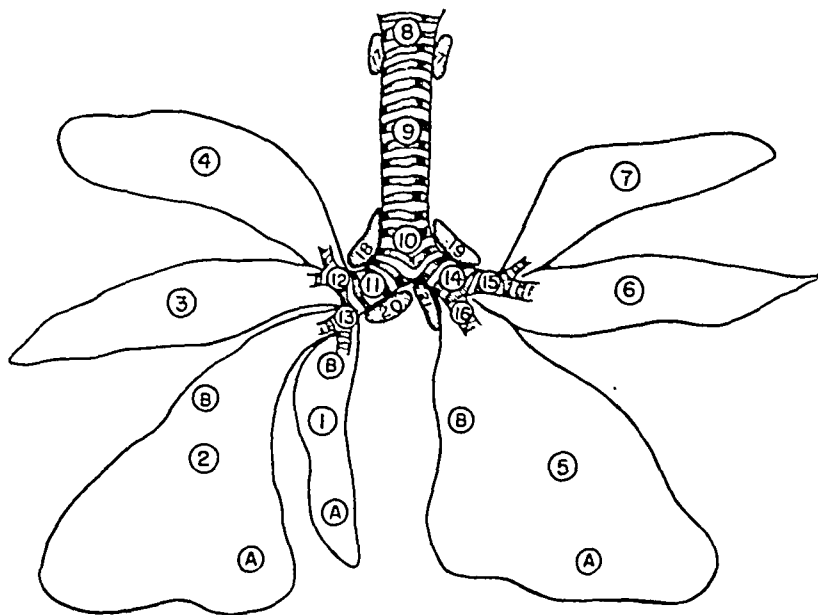


Fig. 1.—Schematic diagram of the lung and regional lymph nodes of dog indicating areas of assay.

METHOD

Apparently healthy mongrel dogs were used. The dogs were anesthetized with intravenous Nembutal, 30 mg. per kilogram of body weight. Two methods were tried.

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TABLE I. RADIOASSAY OF NINE DOGS FOLLOWING INSTILLATION OF RADIOGOLD IN BRONCHUS*

No.	DOG NO. AMOUNT OF Au ¹⁹⁸ TIME INTERVAL—DAYS	73 3 MC. 5	74 3 MC. 5	75 3 MC. 5	82 3 MC. 5	71 5 MC. 6	72 5 MC. 6	80 3 MC. 6	76 3 MC. 7	77 3 MC. 7
	Anatomic Location									
1A	Cardiac lobe	0	14,600	140	8	0	0	0	15	10
1B		0	162,000	17,600	95	0	0	2	4	15
2A	Rt. lower lobe	25	220	710	170,000	2	15	6	10,300	977,000
2B		0	65	180	175	2,420	10,500	25	65	70
3	Rt. middle lobe	20,800	120	380	0	15	20	0	0	40
4	Rt. upper lobe	30	0	120	30	0	0	38,300	0	9
5A	Lt. lower lobe	5	40	10	45	0	0	230	0	15
5B		0	710	0	120	0	0	45	8	25
6	Lingula	0	25	9	110	15	0	0	20	30
7	Lt. upper lobe	0	40	9	25	4	0	30	70	35
8	U/3 trachea	•	•	•	•	•	•	•	•	•
9	M/3 trachea	0	0	0	60	8	20	35	15	45
10	L/3 trachea	•	•	•	•	•	•	•	•	•
11	Rt. main bronchus	•	160	650	45	0	0	0	10	180
12	Rt. upper lobe bronchus	•	•	•	•	•	•	•	•	•
13	Rt. intermediate bronchus	•	•	•	•	•	•	•	•	•
14	Lt. main bronchus	0	0	0	0	0	0	0	0	140
15	Lt. upper lobe bronchus	•	•	•	•	•	•	•	•	•
16	Lt. lower lobe bronchus	•	•	•	•	•	•	•	•	•
17	Upper tracheal L.N.	•	•	•	•	•	•	•	•	•
18	Rt. paratracheal L.N.	0	7	35	55	0	2,760	3	35	55
19	Lt. paratracheal L.N.	10	15	0	120	40	0	0	45	35
20	Rt. subcarinal L.N.	0	590	760	6,090	2,400	520	0	10	250
21	Lt. subcarinal L.N.	670	140	40	60	75	0	15	1,700	240
22	Heart	0	0	0	20	2	0	15	0	45
23	Liver	0	0	0	50	0	0	0	10	10
24	Spleen	0	8	0	65	0	0	0	0	180
25	Omentum	8	0	1	20	0	0	15	0	20
26	Kidney	0	0	1	30	20	4	0	0	30
	Background	16	16	16	16	17	17	16	18	16

*Colloidal Au¹⁹⁸ instilled in Rt. lower lobe bronchus through a catheter placed under direct vision with bronchoscope. Figures are the count/minute/gram tissue of organ, corrected for decay.

0—Count below background.

•—No specimen.

TABLE II. RADIOASSAY OF ELEVEN DOGS FOLLOWING INSTALLATION OF RADIOGOLD IN BRONCHIUS*

DOG NO. AMOUNT OF Au ¹⁹⁸ TIME INTERVAL—DAYS	88 3 MC. 12	93 3 MC. 12	91 3 MC. 12	95 3 MC. 12	96 3 MC. 12	97 3 MC. 12	98 3 MC. 12	84 3 MC. 14	86 3 MC. 14	78 20 3 MC.	83 3 MC. 20
Anatomic Location											
No. 1A Cardiac lobe	180	0	0	0	0	0	150	0	800	1,540	0
1B	260	0	0	570	1,450	170	970	140	65	120,000	65
2A Rt. lower lobe	6,300	40,000	41,200	85,300	92,700	55,200	97,100	74,300	315	0	29,500
2B	0	5,300	0	180	0	0	300	65	20,700	4,520	330
3 Rt. middle lobe	200	0	0	25	170	20	35	150	340	250	210
4 Rt. upper lobe	0	0	0	100	25	0	0	210	280	0	0
5A Lt. lower lobe	0	0	0	450	150	0	180	0	0	0	0
5B	25	65	15	120	0	90	85	410	0	1,470	0
6 Lingula	0	0	0	140	0	450	60	140	170	0	0
7 Lt. upper lobe	0	0	130	220	0	350	15	140	250	360	330
8 U/3 trachea	0	35	0	0	380	200	150	450	0	0	0
9 M/3 trachea	0	0	0	0	0	0	0	0	0	0	0
10 L/3 trachea	0	365	50	0	320	0	55	230	000	0	0
11 Rt. main bronchus	0	0	0	0	0	0	0	0	0	0	0
12 Rt. upper lobe bronchus	0	0	0	0	0	0	0	0	0	0	0
13 Rt. intermediate bronchus	115	0	0	900	00	200	0	0	0	0	0
14 Lt. main bronchus	0	0	0	0	0	0	0	0	0	0	0
15 Lt. upper lobe bronchus	0	0	0	0	0	0	0	0	0	0	0
16 Lt. lower lobe bronchus	0	0	0	0	0	0	0	0	0	0	0
17 Upper tracheal L.N.	0	0	0	0	320	0	230	270	22,800	3,850	41,500
18 Rt. paratracheal L.N.	0	310	370	300	130	0	0	2,300	0	1,000	500
19 Lt. paratracheal L.N.	60	120	760	0	0	200	0	0	4,400	940	32,600
20 Rt. subcarinal L.N.	610	1,370	0	11,100	4,520	5,000	2,850	720	180	6,780	14,600
21 Lt. subcarinal L.N.	260	60	65	120	210	14,600	15	70	0	770	0
22 Heart	0	150	0	65	0	4	60	0	0	0	0
23 Liver	0	0	150	0	0	0	450	100	100	0	0
24 Spleen	80	0	0	200	150	0	10	200	0	0	0
25 Omentum	0	0	0	0	10	135	0	180	0	0	0
26 Kidney	15	60	0	0	0	270	40	0	150	880	760
28 Background	15	17	17	16	15	16	15	16	16	18	16

*Colloidal Au¹⁹⁸ installed in Rt. lower lobe bronchus through a catheter placed under direct vision with bronchoscope. Figures are the count/millieci/gram tissue of organ, corrected for decay.

0—Count below background.

—No specimen.

TABLE III. RADIOASSAY OF EIGHT DOGS FOLLOWING INJECTION OF RADIOGOLD INTO MUCOSA OF BRONCHUS*

No.	DOG NO. AMOUNT OF Au ¹⁹⁸ TIME INTERVAL—DAYS	105 2 MC. 5	115 2 MC. 5	111 2 MC. 5	116 2 MC. 5	118 2 MC. 5	119 2 MC. 5	120 2 MC. 5	117 2 MC. 5
Anatomic Location									
1A	Cardiac lobe	150	30	130	0	30	15	55	60
1B									
2A	Rt. lower lobe	920	0	25	15	54	0	7	10
2B									
3	Rt. middle lobe	50	20	55	35	40	85	0	0
4	Rt. upper lobe	0	0	35	18,600	20	20	20	0
5A	Lt. lower lobe	10	0	9	35	15	30	4	30
5B									
6	Lingula	20	0	20	250	20	25	9	20
7	Lt. upper lobe	0	0	15	20	20	50	6	0
8	U/3 trachea	55	60	0	65	30	8	35	0
9	M/3 trachea	7	0	80	0	5	50	120	120
10	L/3 trachea	100	35	175	400	5	770	60	680
11	Rt. main bronchus								
12	Rt. upper lobe bronchus	120	190	1,900	0	35	9,500	160	0
13	Rt. intermediate bronchus	15	20,700	18,800	4,400	660	990	43,000	100
14	Lt. main bronchus								
15	Lt. upper lobe bronchus	50	500	9,380	40	15	12,400	210	163,000
16	Lt. lower lobe bronchus	4,100	95,000	1,650	63	2,540	37,600	33,000	34,000
17	Upper tracheal L.N.		17,000	30,200	820	44,100	433,000	26,000	8,400
18	Rt. paratracheal L.N.	31,900	53,400	94,300	1,240	510	84,000	11,000	3,240
19	Lt. paratracheal L.N.	31,900	218,000	77,900	390	1,580	224,000	7,400	6,900
20	Rt. subcarinal L.N.	124,000	223,000	197,000	35,300	1,680	610,000	278,000	3,240
21	Lt. subcarinal L.N.	12,200	205,000	196,000		7,530	151,000	173,000	153,000
22	Heart	2	30	110	30	8	45	125	40
23	Liver	10	70	100	0	550	140	190	80
24	Spleen	9	15	20		220	60	130	80
25	Omentum	7	0	20	40	0	20	50	15
26	Kidney	3	9	15	0	4	0	20	0
	Background	16	16	16	16	16	16	16	16

*Colloidal Au¹⁹⁸ injected into mucosa of Rt. lower bronchus under direct vision with a bronchoscope. Figures are the count/minute/gram tissue of organ, corrected for decay.
 0—Below background.
 —No specimen.



FIG. 2—Dog 59. A, Large area of necrosis and pleural reaction in lower lobe of right lung (37 mc. Au^{198}) and B, sectional surface of necrotic area.

the bronchi contained loose granulation tissue and cellular debris. The epithelial cells of the larger bronchi appeared swollen while the cells of the more terminal bronchi were pyknotic with darkly staining nuclei and often very dense "fibrinoid" membranes. All sections showed heavy peribronchial cellular infiltrate. No significant vascular changes could be detected.

Two dogs were examined fourteen days after instillation; one of these (Dog 86) showed fresh necrosis of the lung. Of two dogs sacrificed after twenty days, one had marked segmental necrosis of the lung. In addition to the necrosis, all animals had pulmonary changes similar to the twelve-day group.

One dog (Dog 89) was examined sixty-one days after the instillation of 35 mc. of colloidal Au^{198} . The posterior basal segment of the right lower lobe was firm, gray-white, and noncrepitant. The visceral pleura in this area was gray, opaque, and greatly thickened (Fig. 2). Multiple sections were examined from this area (Fig. 3), the surrounding lung, the left lung, and the regional lymph nodes. There was extensive necrosis of the grossly abnormal area with only cell shadows remaining and with practically no leukocytic reaction. This area contained numerous pigmented macrophages. In other areas there was fibroblastic proliferation and scarring, or organization of the necrotic tissue. Many of the fibroblasts were large and of irregular shape. There was marked proliferation of new capillaries with large endothelial cells throughout the areas of organization. The adjacent lung showed fibrous thickening of the walls of the air sacs and the various changes described in the previous series of low activity animals.

The larger bronchi to the involved segment showed no significant change; however, the more terminal bronchi all showed destruction of the epithelium with organizing granulation tissue in the lumen. There was some regeneration of the epithelial cells with numerous large atypical forms and poor cellular organization. The blood vessels showed marked changes in the nature of proliferative and obliterative endarteritis and endophlebitis, with organizing thrombi. Branches of all sizes were involved. The pleura was greatly thickened by well-organized, young fibrous tissue. The lymph nodes varied from 0.4 to 1 cm. Microscopically they were of normal cellularity with germinal follicles within normal limits. The only detectable changes were: a slight increase in the number of plasma cells, moderate scarring, and focal conglomerations of reticulum cells. These changes were considered to be of a nonspecific nature. The liver was entirely within normal limits.

Dog 90, receiving 15 mc. colloidal Au^{198} , and Dog 91 (Fig. 4), receiving 25 mc., were both examined after sixty-one days. The gross and microscopic findings in these two dogs were similar in all respects to the previously described, high dosage animal.

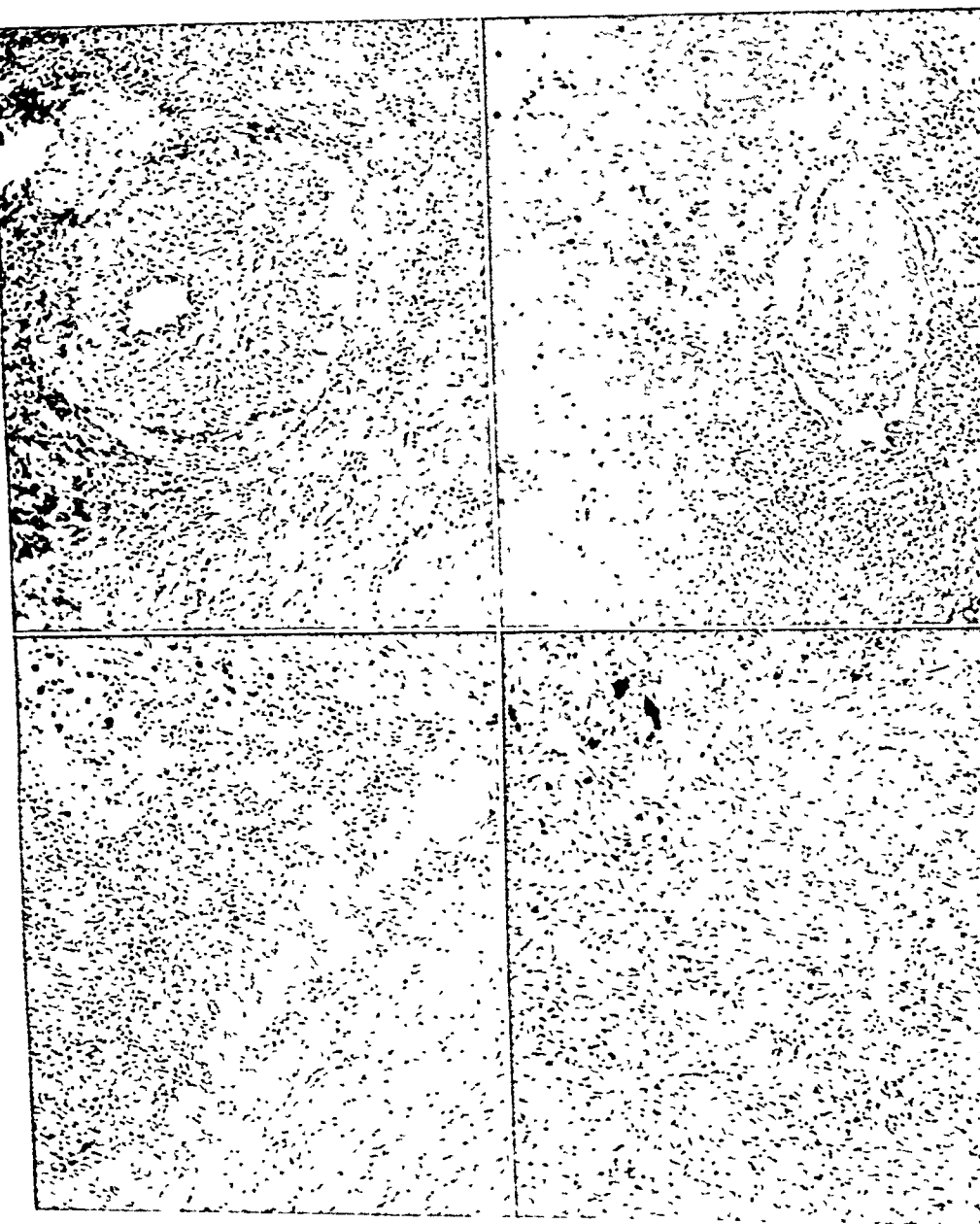
DISCUSSION

Several reports on the use of isotopes in effecting localization of radiation in the lungs have been presented in recent years.

Zn^{63} and colloidal Au^{198} have been introduced through a heart catheter directly into the pulmonary artery or its branches and localization of radio-

A.

B.



C.

D.

Fig. 3.—Photomicrographs of lungs instilled with radiogold. A, Dog 90, typical vascular change adjacent to area of necrosis; B, Dog 90, area of necrosis and changes in a small bronchus. Gold pigment can be seen as small black particles. C, Dog 91, fibrous thickening of pleura in lower left corner, necrosis of the lung and particles of gold; D, Dog 89, new scar tissue in irradiated area of lung.



Fig 4—Dog 91 A, Large area of necrosis and pleural reaction in lower lobe of right lung (25 mc Au^{198}) and B, sectional surface of necrotic area

activity in the segment of lung supplied by the vessel has been reported.⁷ Colloidal Au¹⁹⁵ has been placed in the trachea of dogs lying on one side. This resulted in high levels of activity in the lung on the dependent side and eventual concentration in the mediastinum.⁸ Colloidal Au¹⁹⁵ has been placed in the pleural cavity with resultant high levels of activity on the pleural surfaces of the lung and minimal activity in other organs.⁶

In these experiments we produced maximum localization of activity in the lung by the instillation method. A skilled bronchoscopist should be capable of localizing the segment of lung to which the isotope is delivered. In the event of a bronchus obstructed with carcinoma, it is conceivable that the instillation of an isotope may produce sufficient radiation to shrink the tumor and open the bronchus. The injection method produced extreme localization in the hilar lymph nodes. It is of great interest that the levels in the nodes were even higher than at the site of injection. A combination of the two methods may be the means of delivering sufficient radiation to afford a degree of palliation to the patient with far-advanced carcinoma of the lung.

It is important to remember that these were healthy dogs without carcinoma. In the event that the lymphatics are "plugged" with metastatic emboli, it is quite possible that the localization in the lymph nodes would not be as concentrated, or may not have resulted at all. The only way we know to prove this would be by clinical application and trial.

SUMMARY AND CONCLUSIONS

1. A colloidal solution of Au¹⁹⁵ was instilled through a catheter into a selected segment of a lung in twenty dogs.

2. Assay of these dogs, sacrificed at various time intervals, revealed localization of activity within the selected segment of lung and regional lymph nodes. Histologic studies showed radionecrosis produced in proportion to the amount of isotope instilled in the segment of lung. Only minor changes were seen in the lymph nodes.

3. A colloidal solution of Au¹⁹⁵ was injected into the mucosa of the intermediate bronchus of eight dogs. Assay revealed extremely high levels of concentration of radioactivity in the regional lymph nodes, a lower level at the site of injection, and negligible activity elsewhere.

4. These results suggest the possibility of a clinical trial in patients with inoperable bronchiogenic carcinoma. Palliation might be afforded these patients by using a combination of these methods.

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DISCUSSION

DR. J. KARL POPPE, Portland.—Dr. Bryant's report of the intrabronchial injection of radioactive colloidal gold has been of particular interest to me since I used the same method of administration of radioactive material intrabronchially in dogs from 1945 through 1947. The principal difference was that I used insoluble radioactive ferric phosphate as a colloidal solution or suspension and was unable to obtain as high a concentration of radioactivity per unit of solution as reported with colloidal gold. Thirty-six dogs were treated with insoluble radioactive ferric phosphate, of which twenty were injected intrabronchially in the manner described by Dr. Bryant.

The early results were extremely interesting in that the concentration of radioactivity found in the peribronchial and mediastinal lymph nodes proved to represent about thirty-five times that remaining at the site of injection in the right lower lobe. In that group about 15 c.c. of a dilute suspension of ferric phosphate contained a total dosage of .5 mc. of radioactivity for each dog. In an effort to increase the total dosage to obtain more than a token amount of irradiation and produce actual tissue destruction a much more concentrated suspension with 50 per cent sediment was used in amounts of 15 to 20 c.c. or about 3 mc. for each dog weighing 5 to 10 kilograms. Eighty per cent of these dogs receiving the more concentrated dosage died, either of asphyxiation before they recovered from the anesthesia or of pneumonia within one or two days.

The accompanying slides demonstrate the marked reaction in the peribronchial and pulmonary tissue with edema and cellular infiltration and finally fibrosis. The same reaction is noted in the lymph nodes with edema and loss of follicle formation, but not complete destruction of the lymphocytes. The ferric phosphate particles are especially conspicuous in the tissues prepared with iron stains.

My own experiences with the intrabronchial route for injection of suspensions of insoluble radioactive ferric phosphate were somewhat disappointing as a potential means of irradiating bronchiogenic carcinomas, either in the lungs or mediastinal lymph nodes. It was impossible to apply sufficient quantities of irradiation even to the normal unobstructed bronchus and lung to produce tissue destruction without destroying the animal through suffocation or pneumonia. Perhaps the higher concentration or irradiation per cubic centimeter of injected material obtained by the use of colloidal gold will permit further exploitation of this approach.

DR. JOHN S. HARTER, Louisville.—I think the important idea included in this paper was the fact that the large dosage could be concentrated in the mediastinal lymph nodes by submucosal injection. I doubt very much if the localized injection of the lung itself would be of much value. What will happen in patients with bronchiogenic carcinoma no one can say until we try the method out, but it certainly is worth a trial.

I remember some years ago when I was in Churchill's laboratory, we became interested in attempting to study the lymphatics by Thorotrast. The first animal injected revealed a beautiful pattern of the lymph vessels and nodes of the injected limb as shown by a roentgenogram of the limb. However, the lymph nodes and vessels could not be regularly filled with Thorotrast and the work was discontinued. We thought for a while that we had a method of injecting a radioactive material, thorium, into the lymph nodes some twenty years before the present-day radioactive isotopes became available.

The method presented by Dr. Bryant worked consistently in the normal animal. I think that is the important point of the paper that he presented.

THE ABILITY OF THE PULMONARY VASCULAR SYSTEM TO INFLUENCE THE SPREAD OF TUMOR EMBOLI

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THE interposition of the pulmonary vascular bed between the lymphatic and venous streams on the one hand and the systemic arterial circulation on the other almost certainly inhibits the movement of a certain proportion of migrating neoplastic cells from their points of origin to distant regions of the body. But whether this vascular system exerts a significant obstructive force to metastasizing cancer, for example, as do the sinuses in a lymph node, or whether it captures migrating cells only incidentally is not clear.

The ordinary type of extensive, diffuse, metastatic tumor in the lungs is observed frequently. Moreover, the extreme varieties of metastases are not uncommon: the isolated, solitary deposit that lends itself to surgical removal with long-term survival of the patient, and the type which presents that curious situation where although significant pulmonary disease would be expected to be present, yet at autopsy the metastasizing process seems to have skipped the lungs in favor of other organs.

It is this latter phenomenon, the apparent ability of a tumor to circumvent the lungs, that has excited the curiosity of clinicians and pathologists for many years. Harris¹ has traced the theories of paradoxical emboli to two cases reported by Litten (1880) and Cohnheim (1889) in which a patent foramen ovale was present. He calls these theories absurd, yet credits Cohnheim with stating that, "The locality to which the detached thrombi are transported is determined by anatomical conditions alone." In 1937, Walther² suggested that the lack of lesions in the lungs could be explained by a differential filtering capacity of the pulmonary vascular system. Later³ he reported histologic studies of lungs from patients where distant spread of malignant tumor had occurred with little, if any, clinical or radiologic evidence of pulmonary metastases. Yet he found microscopic foci of tumor cells in a number of the lungs, and he proposed that these foci served as sources of tumor emboli for other parts of the body without undergoing appreciable growth themselves. It was not explained, however, how a dormant tumor could produce emboli.

Although the Harris review pointed out that the essential structure of the vertebral venous system was recognized by anatomists many years ago, it was Batson,⁴ in 1940, who emphasized its character and elaborated upon its possible

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clinical importance in the spread of malignant tumors. Subsequent to his reports it was observed by us and others that tumor could be directed into the vertebral column of experimental animals through the vertebral venous system without first passing through the lungs.^{5, 6}

This explanation for the paradoxical situations did not seem entirely satisfactory, and attention again was directed to the naturally occurring variabilities in the pulmonary arteriovenous communications because of the work of Prinzmetal and his associates⁷ whose experimental studies on rabbits, dogs, and cats with glass spheres of various diameters indicated that normal shunts existed and that they were 160 to 290 microns in diameter in the rabbit lung. Tobin and Zariquiey⁸ performed a similar study on human lungs by perfusing glass spheres of various sizes through the pulmonary artery with saline solution and collecting the perfusate from the pulmonary vein. Spheres up to 500 microns in diameter were recovered from 11 of the 23 specimens examined. They demonstrated the anatomic location of the shunts by radiographs of lungs injected with radiopaque media, by dissections of latex injected lungs, and by study of casts of lungs. Shunts were not present in the hilar region or hilar blood vessels. The ones of 500 micron size were at the apex of the lobular subdivisions of the bronchopulmonary segments. Shunts in the range of 50 to 100 microns were at the level of the smaller bronchi and the smallest, 20 to 25 microns, near the alveolar sacs. Shunts up to 200 microns in diameter also occurred in the pleura.

These investigations, however, have not considered other factors that may be important such as the variabilities that can occur in the constituents of the blood that is bearing the tumor emboli, nor have they considered the contractility of pulmonary arterioles, another natural feature that may affect the movement of emboli through the lungs.

Early in our work with the transplantable V_2 rabbit carcinoma, we observed that suspensions of the tumor injected intravenously caused immediate death of 70 per cent of the animals from pulmonary thromboses and that the rabbits could be protected from this catastrophe by various antithromboplastic agents such as heparin, Dicumarol, and a soybean trypsin inhibitor.⁹ A natural development of these observations was a study of the effect of one of these agents, heparin, upon the distribution of intravenously administered V_2 tumor suspensions and upon the growth of this neoplasm.

Experimental Procedures.—Adult domestic white rabbits were employed. One to ten suspensions of the V_2 tumor in physiologic saline solution were prepared, and all injections were made into a marginal ear vein with a No. 23 gauge needle. The amount injected varied between 0.8 c.c. and 1.0 c.c. per kilogram of body weight. Animals were inspected daily. They were sacrificed if death seemed imminent, but every attempt was made to save them for at least eight weeks after injection, although many died spontaneously before this interval was reached. Complete autopsies with the exception of the head and neck were performed on all animals.

Two types of tumor suspension were employed. Minced suspension was prepared by macerating the donor tumor with scissors and agitating it gently with ten volumes of physiologic saline solution and glass beads in an Erlenmeyer flask for twenty minutes. Comminuted suspension was prepared by placing tumor fragments with the requisite amount of saline solution in the Waring Blendor for thirty seconds. Animals injected with these two types of suspensions were considered the control groups. A few of them had serious reactions to the thromboplastic character of the tumor, but lived, while others had no reaction.

The experimental animals were given 500 U.S.P. units (approximately 5 mg.) of heparin sodium per kilogram of body weight five minutes prior to the injection of the comminuted tumor suspension and twice daily thereafter until death. They were weighed every two weeks and the dose of heparin adjusted accordingly.

All rabbits were housed in air-conditioned quarters at a constant temperature of 70° F. and a relative humidity of 40 and fed a standard diet of Purina Rabbit Chow Checkers.

TABLE I

	MINCED TUMOR	COMMINUTED TUMOR	COMMINUTED TUMOR, HEPARINIZED ANIMALS
No. of animals	17	20	31
Region involved			
Thorax			
Lungs	17 (100%)	20 (100%)	28 (90%)
Diaphragm		1 (5%)	6 (19%)
Chest wall		1 (5%)	3 (10%)
Heart	1 (6%)		3 (10%)
Visceral pleura			2
Abdomen			
Liver	4 (24%)	8 (40%)	17 (55%)
Kidney		2 (10%)	10 (32%)
Omentum & mesentery		1 (1%)	2 (6%)
Spleen			2
Subcutaneous tissue			4 (13%)
Skeletal muscle		3 (15%)	6 (19%)
Paraplegia			7
Quadriplegia			1

Results.—Table I shows the striking difference in the distribution of tumors found post mortem in the three groups. Only two organs other than the lungs were involved by tumor when the minced suspension was employed. The one case of heart involvement appeared to be a mural tumor thrombus in the right ventricle that invaded the myocardium secondarily. The involvement of the lungs was of a massive character in all animals, and in some instances it was so great that only a minimum of normal pulmonary tissue could be found at autopsy (Fig. 1). The liver involvement was much less extensive. One animal had only one liver nodule, for example, and another only two.

The mean length of life of the three animals that died spontaneously was thirty-nine days, and of the fourteen that were sacrificed it was sixty days.

Comminution of tissue in the Waring Blendor is a destructive process in the sense that the integrity of the tissue mass is quickly destroyed. The V₂

tumor can tolerate this vigorous treatment for at least three minutes, however, and still grow when transplanted. The procedure produces fragments of a smaller size and a greater proportion of single cells than can be obtained by mincing and agitating. Thus, the wider distribution of tumor deposits might have been anticipated when comminuted tumor rather than when minced tumor was used. The single cases of chest-wall and diaphragm involvement probably represented secondary invasion from the lung. One of the livers had extensive involvement with many nodules. Another had only a single nodule, 6 by 4.5 by 5 cm. in size, but the lungs from that animal were extensively involved. A third had only two nodules, but one was 4 by 4 cm. There was only a single nodule present in one of the two kidneys, whereas multiple nodules were present in the other. The skeletal muscle deposits were all in the abdominal wall.



Fig. 1—Characteristic massive pulmonary involvement in control groups

The mean length of life of the nine animals that died spontaneously was forty-six days, and of the eleven that were sacrificed it was sixty-five days.

The first outstanding feature of the distribution in the heparinized group was that three animals had no tumor in the lungs but did have tumor elsewhere, two in the liver, and a third in the liver and kidney. This was an observation of the gross tissue only since the lungs were not subjected to serial sections. Two other animals had nothing but a single deposit in the substance of pulmonary tissue and a few tiny deposits in the visceral pleura (Fig. 2).

Whereas the pulmonary involvement in the two control groups was characterized as massive, there were many heparinized animals that had only from

two to five nodules, some of which were only 2 to 4 mm. in diameter. The diaphragm and chest wall tumors were all from implantation and not secondary invasion from the lung. The three cases of heart involvement seemed to be from direct implantation in muscle rather than development from a mural thrombus as occurred in the first control group. The liver and kidney disease was characterized by the presence of multiple nodules. Their size ranged in general from 1 to 2.5 cm., although many were smaller and some were larger. One of the two spleens involved contained only a single tumor, whereas the other contained several. The skeletal muscle implants were distributed in the muscles of the trunk and not of the extremities. Three of the animals had so many implants that the process could be described only as diffuse carcinomatosis.

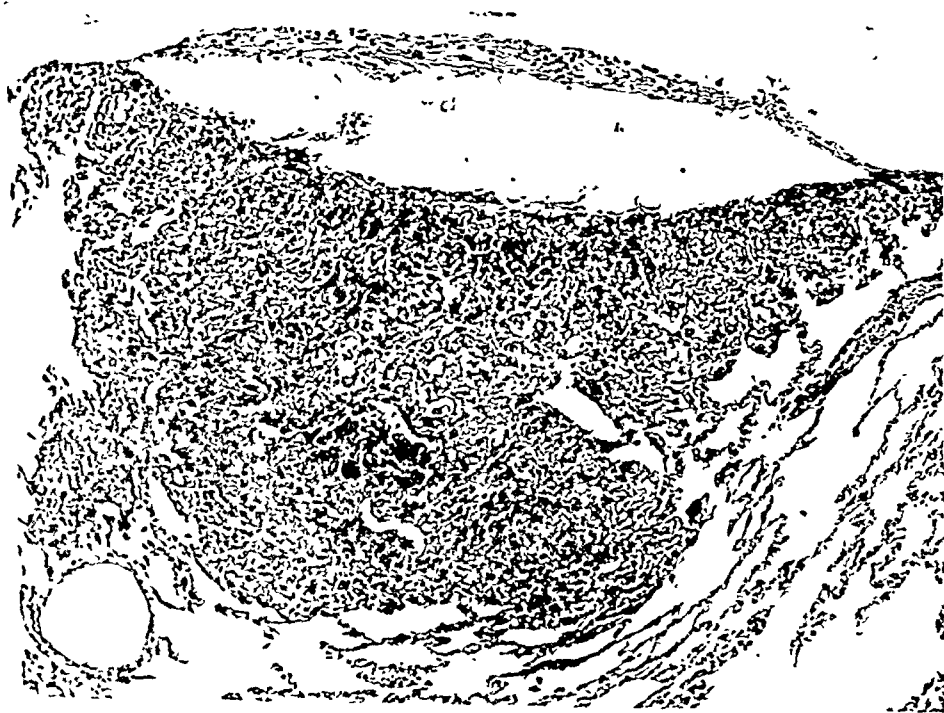


Fig. 2.—Tiny, subpleural tumor nodule frequently encountered in heparinized animals.

The vertebral column complication was of considerable interest. Seven animals became paraplegic and another quadriplegic. Microscopic tumor was found in a lumbar vertebral body in three of the seven and in a cervical vertebra in the latter.

The mean length of life of the twelve animals that died spontaneously was forty-seven days, and of the nineteen that were sacrificed it was sixty-one days.

Seventy per cent of the animals injected with minced tumor, 35 per cent injected with comminuted tumor, and 32 per cent of the heparinized animals had lung involvement only at autopsy.

TABLE II

ANIMAL GROUPS	GROWTH	NO GROWTH	TOTAL
Controls	37 (80.4%)	9	46
Heparinized	31 (79.5%)	8	39
Totals	68	17	85

Heparin had no effect on the rate of takes of the tumor transplants (Table II).

DISCUSSION

Under ordinary circumstances most of the cellular material in the comminuted tumor suspensions should pass readily through the pulmonary vascular system if the size of the arteriovenous communications reported by Prinzmetal and his associates is correct. Many phase microscopy measurements were made of the particles in the comminuted suspensions, and a few cell masses as large as 440 microns in diameter were found. However, 90 per cent of them were less than 240 microns and 60 per cent were between 40 and 90 microns in diameter. As would have been expected, there were many individual cells. They varied from 8 to 20 microns in diameter, the difference in size being explained by differences in the amount of cytoplasm. In view of the theory of Fisher and Holloman¹⁰ that a colony of six cells is a critical-sized colony for successful growth, we do not believe a single cell of this tumor will establish itself and grow.

The venous system of the rabbit is an extremely labile and adaptable structure. If the inferior vena cava, for example, is ligated and divided, collateral venules will have developed between the divided ends of this vessel within twenty-four hours. Furthermore, the venous system of the neck is a veritable maze of anastomosing channels not only between vessels of the same system, but also between the superficial and deep cervical elements. It might be assumed, then, that the injected material could by-pass the lungs through these collaterals and go directly to other organs.

This system in the neck was studied extensively in another experiment by one of our associates (Crockett) with liquid latex injections and dissection, and with vinylite plastic injection and hydrochloric acid digestion with study of casts thus obtained. If both jugular veins were divided and as much as 20 c.c. of material were injected into an ear vein with considerable pressure, the latex or vinylite appeared in the vertebral veins as low as the lumbar region. However, when the jugular veins were free and competent, the injected material always proceeded directly to the heart. The quick movement of injected material from a marginal ear vein to the right heart and lungs under normal circumstances was verified radiographically in a series of living animals (Fig. 3). An amount of Thorotrast commensurate with the volume of tumor suspension customarily injected was used, and it proceeded directly to the heart in every instance without going to other organs or leaving the innominate veins.

For these reasons we believe that the cell suspensions likewise proceeded directly to the right heart without entering other organs first and that they contained cell masses of a size that could pass through the lungs.

The thromboplastic effect of this tumor was variable. Most animals died within two minutes after its injection. Others had severe reactions characterized by respiratory difficulty and convulsions, but lived and a few had no ill effects whatsoever. Immediate autopsies on those that died showed clots in the right heart and pulmonary artery. Some were so massive that they extended in continuity from the auricle through the ventricle into both pulmonary arteries. All preparations of this tumor had a certain degree of thromboplastic activity.¹¹ We believe, therefore, that even though some animals survive the intravenous injections (as did those in the two control groups) they have a certain degree of immediate pulmonary intravascular coagulation; and that the clots may prevent cell masses from passing the pulmonary arteriovenous barrier to the left heart arterial circulation.



FIG 3—Distribution of 3 c.c. of Thorotrast injected into a marginal ear vein. Exposure was made at conclusion of the injection.

Heparinization inhibits the blood-clotting mechanism. None of the animals that was given the protective dose of 500 U.S.P. units per kilogram five minutes before the intravenous injection of the tumor succumbed to its thromboplastic property. Estimations of the clotting time of rabbits' blood are so notoriously inaccurate¹² we have attempted no analysis of it. From studies now in progress, however, we have learned that this amount of heparin influences the clotting mechanism for the subsequent two and one-half hours and will protect all ani-

mals for two hours against the lethal effect of the tumor suspensions. In all likelihood it is the initial dose of heparin alone that inhibits clotting in the pulmonary vessels and thus allows tumor emboli to pass through the pulmonary arteriovenous communications to the systemic arterial circulation. The later injections of heparin are probably unimportant in this respect.

Applications of these studies to the human beings are not yet clear. However, if arteriovenous communications in the human lung as large as 500 microns do exist under otherwise normal conditions, emboli of sufficient size for growth could slip through the lung to the systemic arterial system, particularly if the blood clotting were prolonged to a degree that the embolus would not be encompassed with an obstructive clot.

CONCLUSIONS

The passage of tumor emboli through the lungs of rabbits is determined by the size of the emboli, the size of the pulmonary arteriovenous communications, and the coagulability of the blood.

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BRONCHIAL RESECTION AND ANASTOMOSIS

PAUL W. GEBAUER, M.D.

HONOLULU, T. H.

THE receptiveness of the central tracheobronchial tree to proper surgical procedures is exceptional, and the integrity of lung tissue distal to bronchial lesions is frequently persistent. Consequently, direct surgical treatment of such lesions permits the salvage of good lung tissue in distinction to removal of all the lung supplied by a diseased bronchus. In all cases of isolated tracheobronchial disease, and in many cases when such disease is combined with pulmonary parenchymal disease, some type of tracheobronchial procedure should be routinely considered in the contemplation of surgical treatment.

The merit of this conception has been illustrated in previous publications concerning tracheobronchial dermal grafts¹⁻⁴ and bronchial resections^{5, 6}. The purpose of this paper is to present a series of cases illustrating some of the aspects of the technical application of bronchial resection to a variety of tracheobronchial lesions. The cases are summarized in tabular form (Table I).

SLEEVE RESECTION AND ANASTOMOSIS

1. *Lobar Bronchi*.—Healed tuberculous strictures of right upper lobe bronchi were excised and anastomosis performed in Cases 3, 6, and 12. Segmental resections in two patients and localized excision in one were used to treat the coexisting parenchymal disease in distinction to lobectomies. This procedure is very simply applied, and a most gratifying volume of lung tissue can be thereby salvaged. The use of everting mattress sutures in small bronchi is likely to produce an undesirable diminution of the anastomotic lumen; simple end-to-end closure with fine interrupted wire sutures is better. Irregular edges, mucosal tags, dried blood, and secretions tend to accumulate and coalesce along the line of anastomosis. They should be cleaned off bronchoscopically in the early postoperative period to prevent the possibility of their organization and recurrent stenosis (Table I, Case 12).

2. *Main Bronchi*.—In Cases 1 and 8, the right bronchus from the middle lobe stump to the coryna was excised for healed tuberculous stricture, and anastomosis between the distal trachea and lower lobe bronchus performed. An intact, useful, lower lobe was salvaged in each instance. The necessity for removal of the middle and upper lobes undoubtedly facilitated the bridging of the bronchial gaps. Figs. 1 and 2 illustrate Case 8.

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	SEX AGE	DISEASE STATUS BEFORE OPERATION	SURGICAL FINDINGS AND PROCEDURE	P.O. TIME	REMARKS	PRESENT STATUS
Case 1.	F. 26 yr.	Right thoracoplasty 9 yr. before. Active tuberculous right middle lobe. Healed stenosis right main and upper lobe bronchi	No evidence of damage of the lower lobe. Excision of upper and middle lobes, and right bronchus; anastomosis of lower bronchus to trachea	2 yr., 1 mo.	Lower lobe salvaged by bronchial resection, its functional integrity confirmed by the postoperative course. Sputum converted to negative	Home. Working. No symptoms
Case 2.	F. 24 yr.	Active nodular tuberculous left upper lobe. Healed stenosis left upper and distal left main bronchi	Lower lobe grossly normal; left upper lobectomy; excision of distal left main bronchus, anastomosis of lower lobe bronchus to proximal left main bronchus	1 yr., 10 mo.	Good left lower lobe salvaged by excision of main bronchial stenosis. Sputum converted	Home. Working. No symptoms
Case 3.	F. 17 yr.	Old, expanded left pneumothorax. Right pneumothorax. Small cavity apex right lung. Stenosis right upper lobe bronchus	Segmental resection posterior segment right upper lobe. Small sleeve resection of stenosis of right upper lobe bronchus followed by anastomosis	1 yr., 8 mo.	Major portion of upper lobe salvaged by segmental resection and repair of lobar bronchus in distinction to lobectomy	Ambulant ward. Sputum negative. Right lung clear. Bronchus healed
Case 4.*	M. 35 yr.	Left upper lobectomy and dermal graft for stenosis of left main bronchus over 2 yr. previously. Recurrent bilateral tracheobronchitis	Distal portion of left main bronchus including part of graft, and upper lobe stump excised. Lower lobe bronchus anastomosed to proximal main bronchus	1 yr., 8 mo.	Dermal graft failure because of recurrent tracheobronchitis, successfully treated by resection and anastomosis. No further pulmonary excision	Ambulant ward. Sputum negative, but only 4 mo. since antibiotics
Case 5.	M. 44 yr.	Hamartoma right intermediate bronchus, arising from posterolateral wall opposite middle lobe bronchus	Excision of tumor and involved bronchial wall, and superior segment of lower lobe. Bronchial defect closed transversely using superior segment bronchi as a crude flap	1 yr., 7 mo.	Superior segment of lower lobe sacrificed for bronchial structures to fill defect, in distinction to right middle and lower lobectomies	Home. Working. No symptoms
Case 6.	F. 27 yr.	Small tuberculous nodule right lower lobe. Healed stenosis right upper lobe bronchus	Localized excision small "blocked" cavity right lower lobe. Small sleeve resection of stenosis of upper lobe bronchus and anastomosis	1 yr., 6 mo.	2 serious chest lesions surgically cured with practically no loss of pulmonary tissue	Home. Working. No symptoms
Case 7.*	M. 34 yr.	Atelectasis right upper lobe, and occlusion of its bronchus. Severe stenosis of main bronchus at the coryna. Right permanent phrenic paralysis	Right upper lobectomy. Wedge or crescent excision of dense tracheobronchial scar opposite coryna and including upper lobe stump. Repair by transverse closure	1 yr., 6 mo.	Good middle and lower lobes salvaged; bronchial lumen restored by a rather simple plastic procedure, and lobectomy in distinction to pneumonectomy	Home. Working. No symptoms
Case 8.*	F. 37 yr.	Destroyed right upper lobe with a large cavity. Occlusion of right upper and severe stenosis of main bronchus. Fibrosis and nodules middle lobe	Upper and middle lobectomies. Excision of right main bronchus. Anastomosis of lower lobe bronchus to trachea	1 yr., 5 mo.	Reoperation 2 wk. later for persistent air leak; bronchial anastomosis intact; leak from lower lobe near hilum distal to anastomosis	Home. Working. No symptoms
Case 9.	M. 26 yr.	Destroyed right lower lobe with healed stenosis of right lower lobe bronchus. Marked shrinkage of lobe by atelectasis, bronchiectasis and pneumoperitoneum	Right lower lobectomy. Middle lobe bronchus severed with basal segments of lower lobe, then dissected from them and sutured to the intermediate bronchus	1 yr., 4 mo.	Bronchial dissection simplified and middle lobe salvaged by complete bronchial division and anastomosis	Home. Not working. No symptoms

A.

B.



C.

D.

Fig. 1 (Case S).—Preoperative and postoperative planigrams. A, Planigram before operation, showing destroyed right upper lobe with cavity; permanent stenosis of right bronchus at the cor. B, Planigram showing severe stenosis of right bronchus at the cor. C, Planigram showing right upper and middle lobectomies, and excision of stenotic main bronchus. D, Planigram taken at the same time, showing excellent anastomotic lumen of right bronchus.

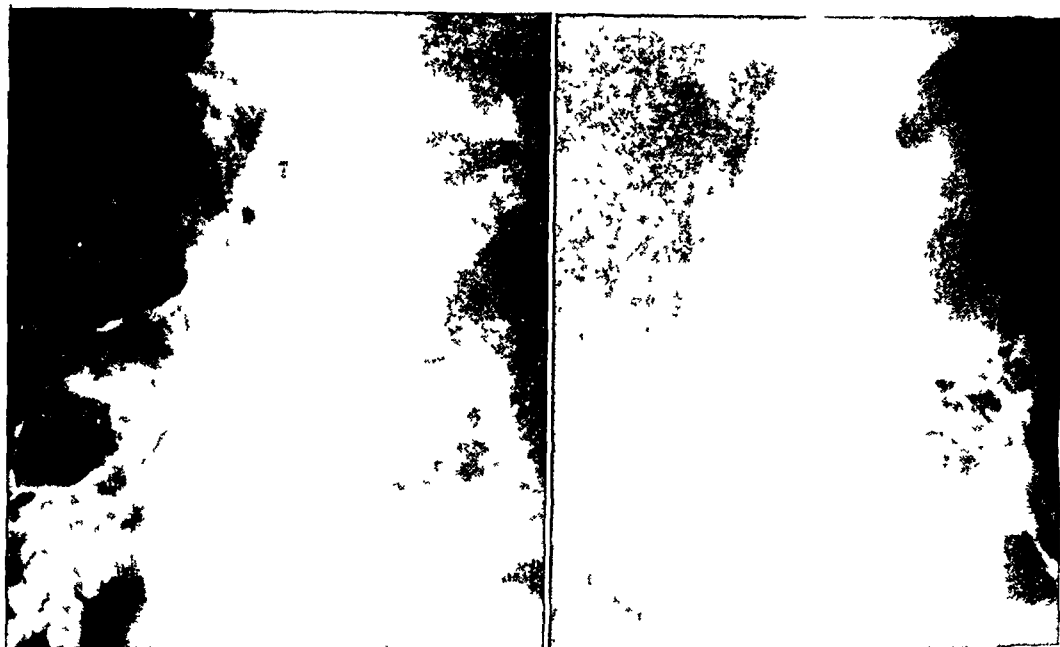
In Cases 4 and 10 dermal grafts of the main bronchi were inserted at the time of upper lobectomy for the correction of main bronchial stenosis. Both patients experienced late recurrent tuberculous tracheobronchitis which responded to further antimicrobial treatment. These are the only bronchial dermal graft failures in my experience, and in each instance it seemed that the recurrent inflammation arose from residual infection in the upper lobe stump. Both patients were treated by partial excision of the grafted main bronchi and upper lobe stumps (Figs. 3 and 4); no further pulmonary excision was necessary.



Fig. 2 (Case 8)—Photograph of surgical specimen. Bronchus, middle and upper lobes right. A slice of the cavity bearing upper lobe has been turned upward. The excised bronchial stenosis is at the lower left.

Case 16* presents an instance of primary tuberculosis in a 2-year-old girl. Three separate caseous lymph node masses were present; one of these had eroded and destroyed the right main bronchus. The right lung was salvaged by anastomosis of the upper-lower lobe bronchial crotch to the trachea. Symptoms had been present for one year, and intermittent obstructive emphysema of the right lung was noted for almost as long. For the present, bronchial anastomosis was successful despite the unquestioned presence of active tuberculous lymph node and bronchial inflammation. This is considered highly important because, in the past, it has seemed reasonable to await bronchial healing before attempting surgical treatment, and this may still be advisable as far as

*This patient was operated on by Dr. W. P. Child at Prompton Chest Hospital. This is a most interesting case and is included in this series with his kind permission.



A

B

Fig. 3 (Case 4) —Bronchograms A, Before operation, marked deformity and puddling of contrast media in grafted left bronchus. New stenosis of right bronchus distal to upper lobe. B, After excision of diseased portion of left bronchus. Line of anastomosis is barely visible, it is just proximal to the superior segment bronchus of the lower lobe which looks like an upper lobe bronchus. However the upper lobe had been removed at the time of the original dermal graft of the main bronchial stenosis.



A

B

Fig. 4 (Case 10) —A, Preoperative bronchogram at time of recurrent tuberculous tracheo-bronchitis involving grafted right bronchus. Some of the supporting wire in the graft is visible. B, Postoperative planigram after excision of recurrent stenosis of right bronchus. Good anastomotic lumen.

the use of dermal grafts is concerned. On the other hand, the period of healing is sometimes prolonged and the distal lobe or lung may become irreparably damaged by the bronchial obstruction during that time. Therefore, if bronchial excision and anastomosis is contemplated, sometimes it may be advisable to proceed with it, despite the presence of only early, or partial, healing of the inflammatory process. Fig. 5 illustrates the patient in Dr. Cleland's case.

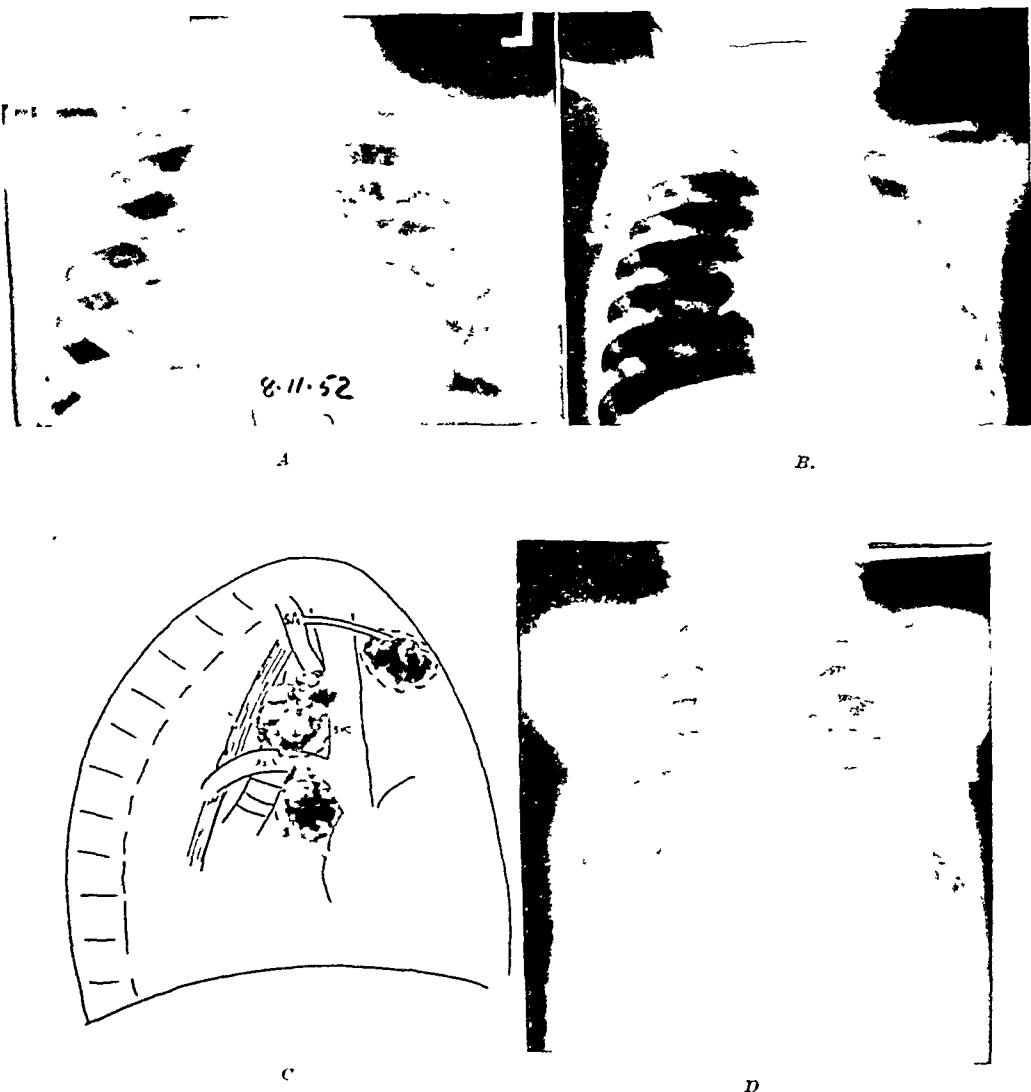


Fig. 5 (Case 16).—A. Primary tuberculosis with mediastinal lymph node involvement. B. Obstructive emphysema of the right lung before operation. C. Composite diagram of lateral mediastinal lymph node mass. The middle one had eroded and destroyed the right bronchus. The right upper and lower lobe bronchi were anastomosed to the trachea. D. Three months after operation, right lung well aerated. (Courtesy of Mr. W. P. Cleland, Brompton Chest Hospital.)

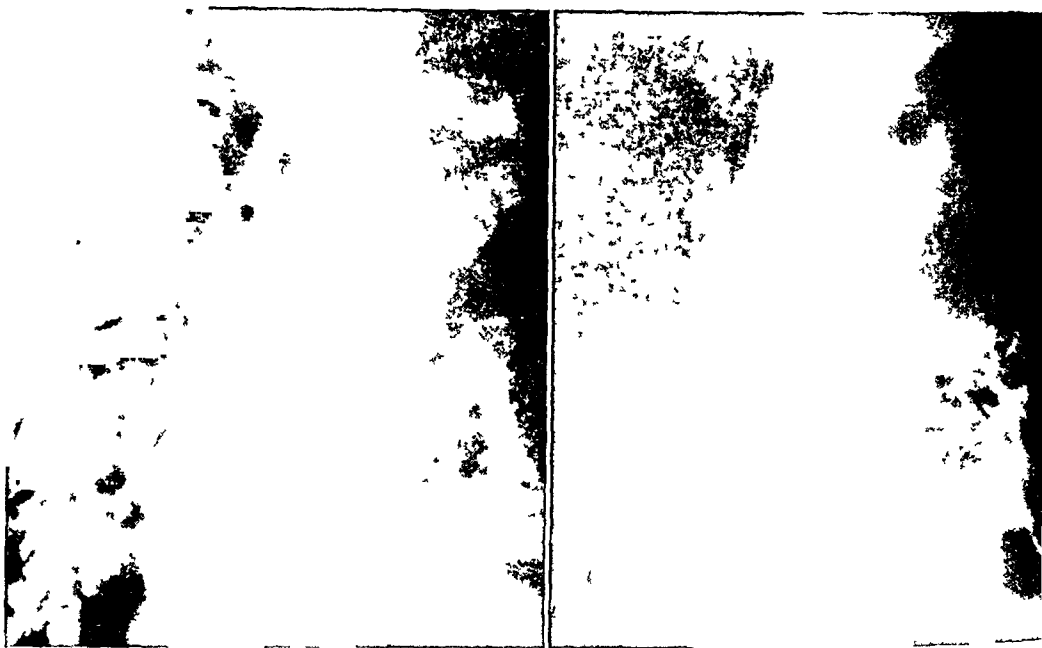


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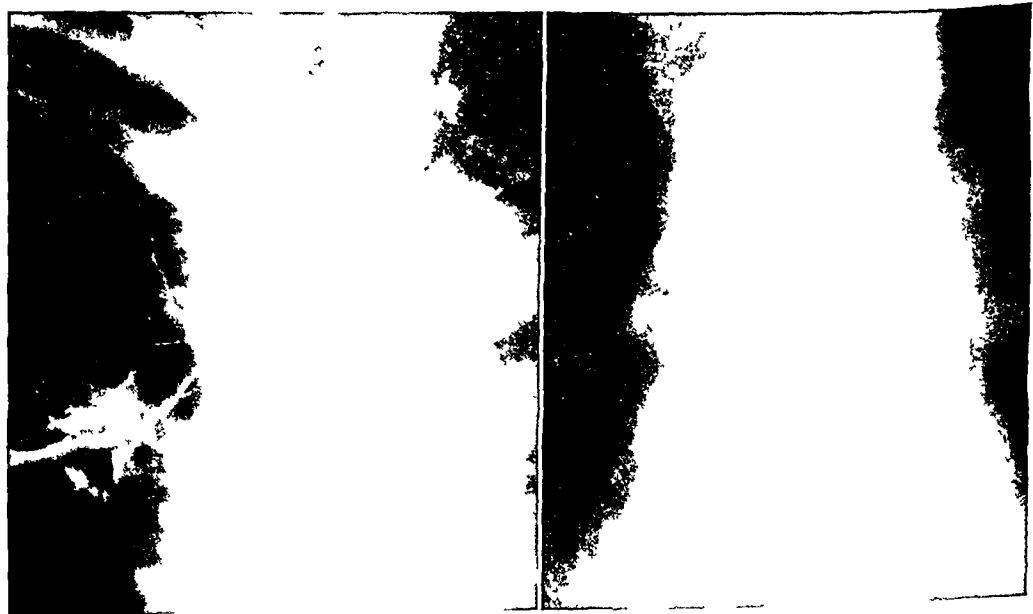


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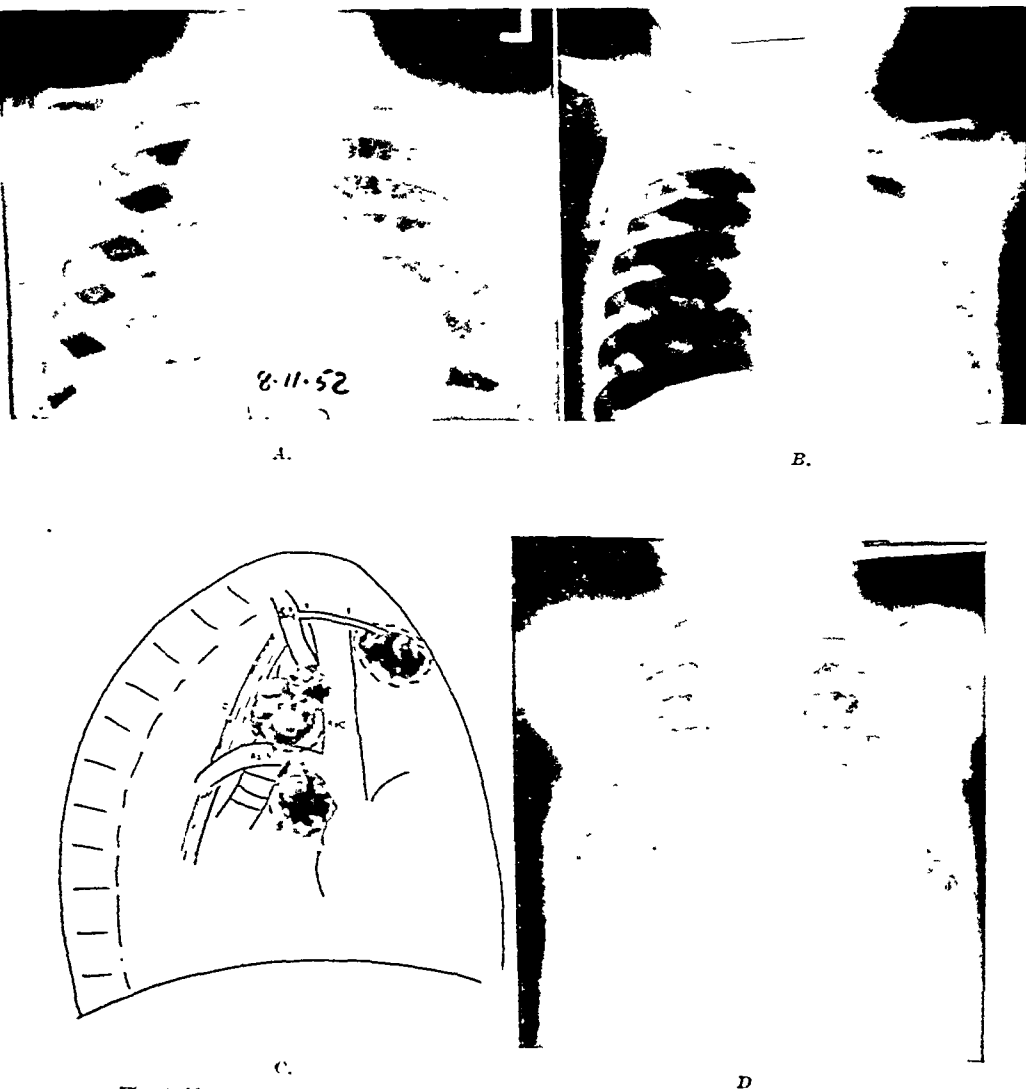


FIG. 5 (Case 16).—A. Primary tuberculosis with mediastinal lymph node involvement. B. View of chest and photograph of surgical specimen which consisted of three separate, caseous, mediastinal lymph node masses. The middle one had eroded and destroyed the right bronchus. The right upper and lower lobe bronchi were anastomosed to the trachea. C. Three months after operation, right lung well aerated. (Courtesy of Mr. W. P. Cleland, Brompton Chest Hospital)

3. *Intermediate Bronchus*.—In Case 15,* a most remarkable bronchial resection and anastomosis was performed. The patient had an adenoma in the distal left main bronchus, opposite the upper lobe orifice, which obstructed the lower lobe bronchi and caused expiratory emphysema of the left lung. As depicted in Figs. 6 and 7, the stem bronchus was transected above the tumor, the upper lobe bronchus lateral to the tumor, the superior segment lower lobe bronchus posterior to the tumor, and the basal bronchi (as a unit) transected below the tumor. The distal upper lobe stump was then sutured to the anterior edge of the basal stump, and the superior segment to the posterior edge. Thus the three divided bronchi were converted to a single stump which was anastomosed to the proximal stump of the stem bronchus. This permitted a wide excision of an adenoma arising at the main crotch of the stem bronchus and salvage of the entire left lung.

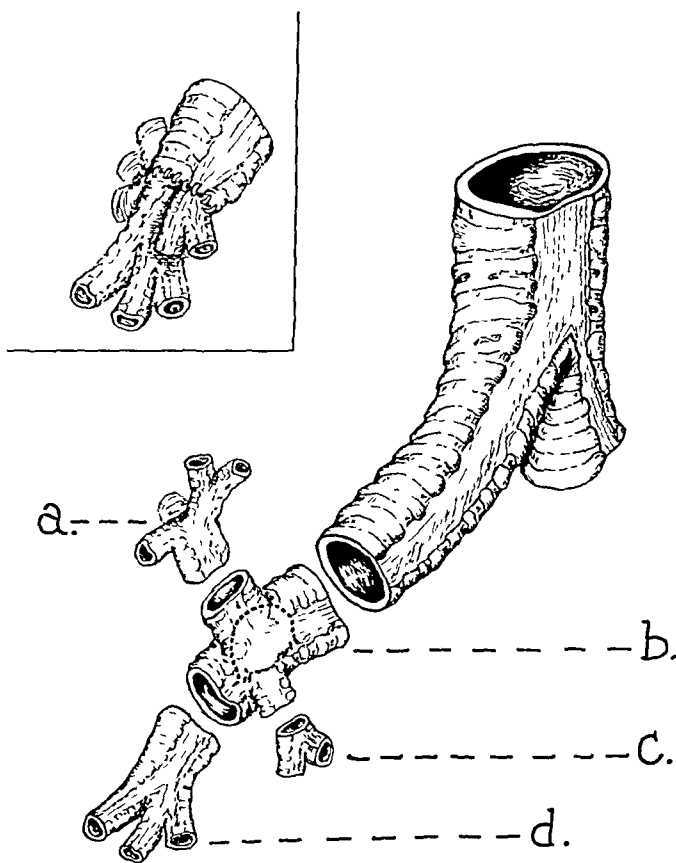


Fig. 6 (Case 15).—Drawing of tracheal bifurcation and left bronchus depicting operative procedure. *a*, Upper lobe bronchus transected just beyond its origin. *b*, Divisionary crotch of left bronchus containing a benign adenoma located by dotted outline. *c*, Divided superior segment of left lower lobe. *d*, Divided basal bronchi of left lower lobe. Inset at upper left shows how the peripheral bronchi were sutured together, and then, as a unit, sutured to the stump of the main bronchus. (Courtesy of Mr. C. J. Officer Brown, Melbourne, Australia.)

*Dr. C. J. Officer Brown of Melbourne, Australia, performed the operation and he has kindly permitted its inclusion in this series.

WEDGE EXCISION

The generous elasticity of tracheobronchial structures permits a marked compensation for severe cicatricial deformities. The uninvolved bronchi neighboring a severe scar, which has resulted from the healing of a destructive process, elongate and dilate. Thus the right intermediate bronchus distal to a dense fibrous scar involving the proximal main and upper lobe bronchi, will usually be almost as long and large as a whole right bronchus. This combination of severe upper lobe stenosis and stenosis of the immediately adjacent main bronchus is rather common and sometimes can be rather simply remedied because of the inherent quality of bronchial structures.

Case 7 is an example. The right upper lobe was atelectatic and destroyed, its bronchus physiologically occluded by a dense scar which incorporated the orifice of the right main bronchus at the coryna. At the time of upper lobectomy,



FIG. 7. (Case 15) — Photograph of surgical specimen. Crotch of left bronchus containing adenoma. The bronchi have been opened anteriorly. *a.*, Edge of transected main bronchus. *b.*, Edge of transected superior segment of lower lobe. *c.*, Edge of transected upper lobe. *d.*, Edge of transected basal bronchi of lower lobe. (Courtesy of Mr. C. J. Officer Brown, Melbourne, Australia.)

3. *Intermediate Bronchus.*—In Case 15,* a most remarkable bronchial resection and anastomosis was performed. The patient had an adenoma in the distal left main bronchus, opposite the upper lobe orifice, which obstructed the lower lobe bronchi and caused expiratory emphysema of the left lung. As depicted in Figs. 6 and 7, the stem bronchus was transected above the tumor, the upper lobe bronchus lateral to the tumor, the superior segment lower lobe bronchus posterior to the tumor, and the basal bronchi (as a unit) transected below the tumor. The distal upper lobe stump was then sutured to the anterior edge of the basal stump, and the superior segment to the posterior edge. Thus the three divided bronchi were converted to a single stump which was anastomosed to the proximal stump of the stem bronchus. This permitted a wide excision of an adenoma arising at the main crotch of the stem bronchus and salvage of the entire left lung.

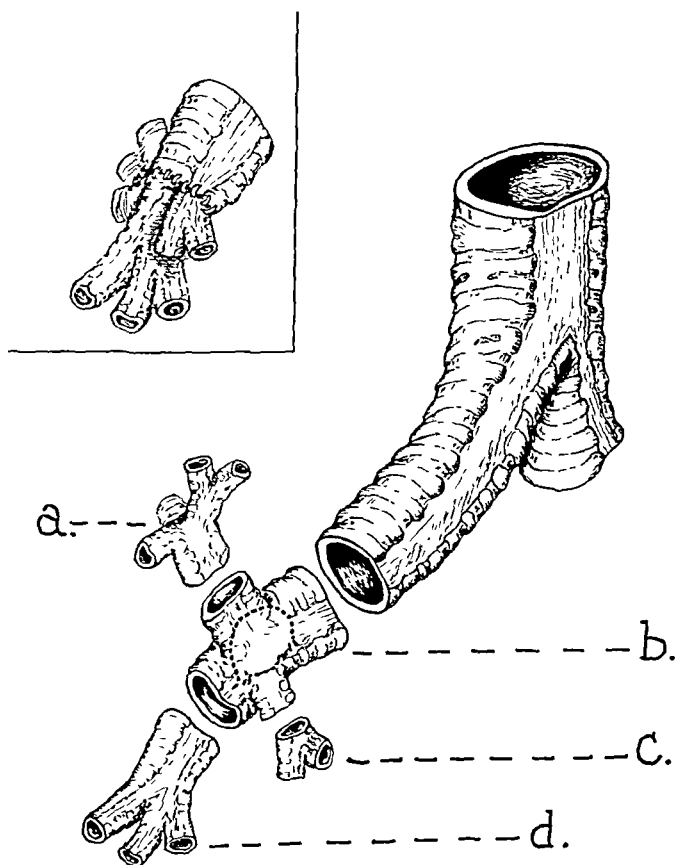
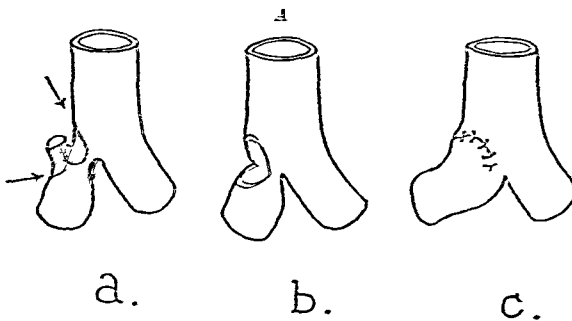


Fig. 6 (Case 15).—Drawing of tracheal bifurcation and left bronchus depicting operative procedure. *a*, Upper lobe bronchus transected just beyond its origin. *b*, Divisionary crotch of left bronchus containing a benign adenoma located by dotted outline. *c*, Divided superior segment of left lower lobe. *d*, Divided basal bronchi of left lower lobe. Inset at upper left shows how the peripheral bronchi were sutured together, and then, as a unit, sutured to the stump of the main bronchus. (Courtesy of Mr. C. J. Officer Brown, Melbourne, Australia.)

*Dr. C. J. Officer Brown of Melbourne, Australia, performed the operation and he has kindly permitted its inclusion in this series.

the upper lobe bronchus and the adjacent stem bronchial scar were excised as a wedge, or a slice of melon, and the lower edge rotated upward to meet the upper edge as illustrated in Figs. 8 and 9. It is advisable, when attempting

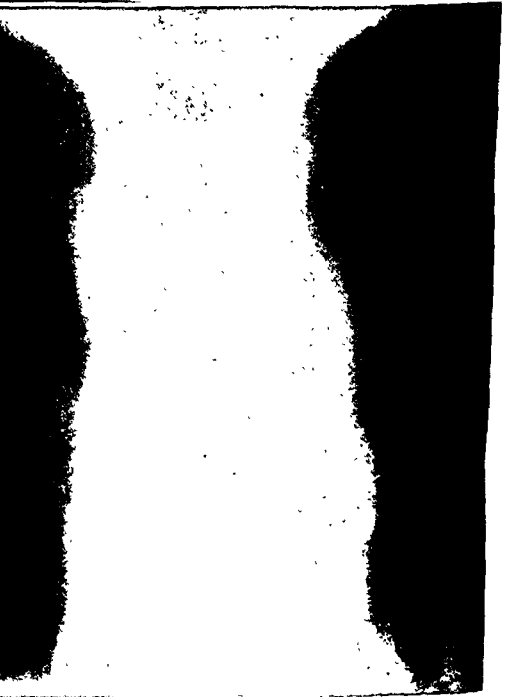
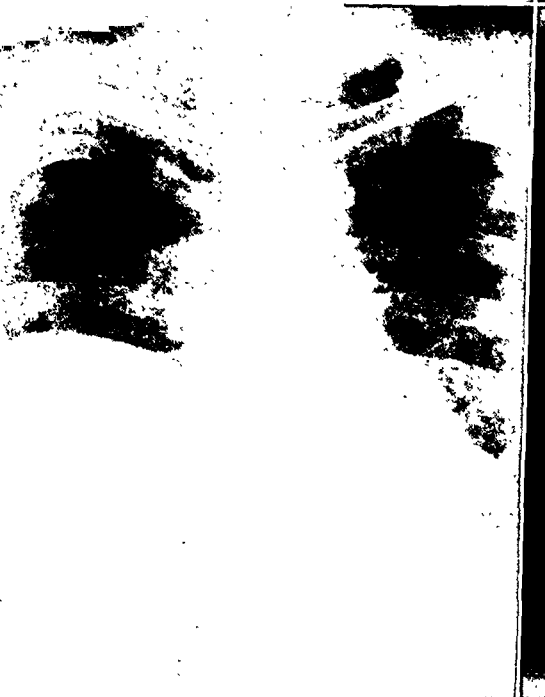
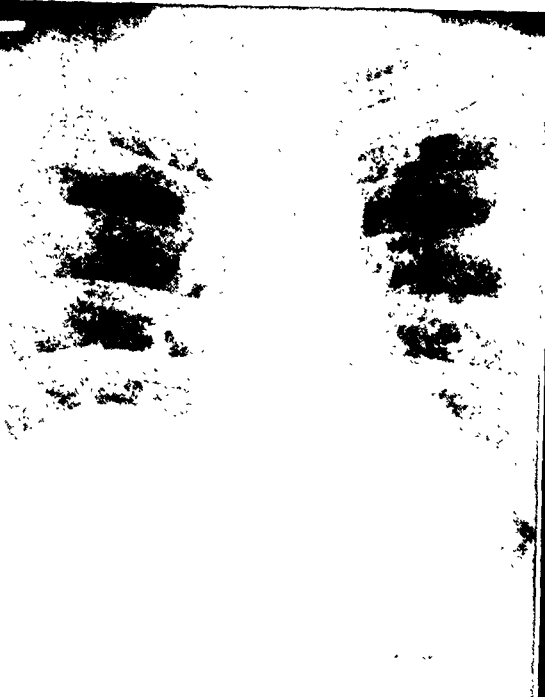


B.

FIG. 9 (Case 7).—A, Photograph of surgical specimen, atelectatic right upper lobe containing chronic cavity. B, Line diagrams depicting use of wedge excision of main bronchial stenosis at the coryna. a, Stenosis of main and upper lobe bronchi. b, Wedge excision of stenosis and removal of upper lobe. c, Rotation of bronchus and transverse closure.

A.

B.



C.

D.

Fig. 8 (Case 7).—Preoperative and postoperative roentgenograms. A, Atelectasis right upper main right bronchus. B, Planigram showing severe stenosis right main bronchus. C, After right upper lobectomy and wedge excision of stenotic segment. D, Same time showing good bronchial lumen.

A.

B.



C

D

Fig 10 (Case 11).—Preoperative and postoperative roentgenograms. A, Acute, suppurative pneumonia, right. B, Almost one year later chronic pneumonia with multiple abscesses has since closed. A large defect of the friable right bronchus was accidentally produced at operation; it was closed by transverse suture. C, Planigram three months postoperative showing good lumen of repaired right bronchus.

bronchial surgery, to place the bronchial structures under tension with fine forceps to appraise them, and to remember that there is a great difference in the bronchi of a collapsed lung in an opened chest, and of an expanded lung in an intact chest.

TRANSVERSE CLOSURE OF BRONCHIAL DEFECT

1. *Simple*.—This procedure is very similar to the preceding category, and is again possible because of the elastic adaptability of the bronchi. Rather large bronchial defects involving less than one-half the bronchial circumference can sometimes be closed transversely causing some bronchial curvature, but, also actually increasing the bronchial lumen. The patient in Case 11 had a bilobectomy for chronic pneumonitis and multiple abscesses in the right upper lobe. A portion of the friable main bronchus was accidentally avulsed with the upper lobe bronchus during attempted isolation of the latter. A large defect of the right bronchus was thus produced which closed surprisingly well by simple transverse suturing. The resulting large bronchial lumen is illustrated in Fig. 10.

2. *With the Aid of Additional Bronchial Tissue*.—Sometimes the closure of a bronchial defect is simplified if a neighboring lung segment is sacrificed and its bronchial stumps used as a crude flap. Case 5, previously reported,⁶ is an example. A hamartoma, and the bronchial wall at its base were excised from the right intermediate bronchus. Rather than resect the whole middle and lower lobes, the superior segment of the lower lobe was removed, and its bronchi used as a crude trap-door flap to assist in a transverse bronchial closure.

COMPLETE OR PARTIAL BRONCHIAL DIVISION TO FACILITATE DISSECTION

This procedure is of particular consequence in salvage of an intact middle lobe when its bronchus is more or less fused to the branch bronchi of a shrunken, atelectatic and bronchiectatic lower lobe. If the bronchus is first divided below the upper lobe, the middle lobe bronchus (to be preserved) can be more easily and safely separated from the lower lobe basal bronchi. Bits of the latter may be left attached to the middle lobe bronchus if necessary. Anastomosis is then performed joining the middle lobe to the proximal right bronchial stump.

In Case 13 the patient had a good, large, hypertrophic middle lobe practically filling the hemithorax, the result of bronchiectatic atelectasis and shrinkage of the upper and lower lobes beginning in childhood, and persisting for at least fourteen years during the period of greatest body growth. Bronchograms revealed a normal left bronchial tree and right middle lobe, with advanced bronchiectasis of the upper and lower lobes (Fig. 11). The procedure described above was necessary to dissect the middle lobe bronchus which arose at the same level and was almost fused to the basal branches of the lower lobe. The value of this salvaged middle lobe is substantiated by its rather large pulmonary artery visible in Fig. 11, D.

The patient in Case 9 had a similar operative procedure. This was an instance of lower lobe destruction by tuberculous stenosis and bronchiectasis. The

marked lower lobe shrinkage was abetted by pneumoperitoneum. Compromise of the middle lobe orifice would probably have occurred with the ordinary treatment of the lower lobe bronchial stumps.

BRONCHIAL RESECTION AND TRANSPLANTATION

I have only twice considered the clinical circumstances likely to demand this procedure, and used it only once. In Case 14, the patient, a 24-year-old woman, experienced a recurrent, severe, ulcerocaseous tuberculosis of the trachea and right bronchus, with no roentgenologically visible disease in either lung.

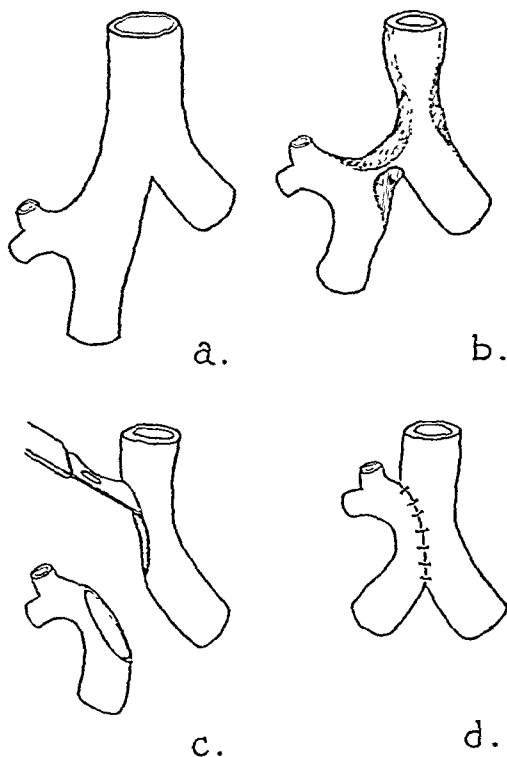


Fig. 12 (Case 14).—Line diagrams of tracheal bifurcation depicting operative procedure used for combined, severe tracheal and right bronchial stenosis. Chest roentgenograms showed no abnormality or disease of the lung fields. *a*, Normal bifurcation for comparison. *b*, Healing tuberculous tracheal stenosis was most severe in the lower one-third; it was by-passed with a long tracheotomy tube. The right bronchus was almost occluded. *c*, The stenosed right bronchus has been excised; the distal bronchus is a large double-barreled structure; the tracheal stenosis is being slit open. *d*, The tracheal circumference has been enlarged by the addition of the right bronchus which has been transplanted and sutured into the tracheal incision.

Antimicrobial treatment was restarted after a lapse of two years. Three months later, during the early healing phase, a tracheotomy with a long cane-shaped tube had to be done to by-pass a severe, asphyxiating stenosis of the lower tracheal third. There was also practical occlusion of the right bronchus at the coryna by a clean, healing stenosis.

Because of the short time that had elapsed since active, caseous tracheitis had been observed, tracheotomy was done with considerable reluctance; inasmuch

A.

B.



C.

D.

Fig. 11 (Case 13).—Preoperative and postoperative chest roentgenograms and bronchograms. *A*, Bronchiectasis and atelectasis right upper and lower lobes, with large bullae of upper lobe, fourteen years before operation. *B*, Preoperative bronchogram showing normal left side, and severe bronchiectasis and shrinkage of upper and lower lobes. *C*, Middle lobe bronchogram shows no significant bronchiectasis. *D*, After excision of upper and lower lobes, and salvage of the middle lobe by bronchial division, dissection and anastomosis. The pulmonary artery of the middle lobe is large which is indicative of its functional capacity.

but there had been complete fracture of the bronchus; the two ends were separated by at least 4 cm., and the space was occupied by fibrous tissue. After both ends were opened, there was a considerable amount of pus which escaped from the lung. I thought she might have bronchiectasis and I therefore did a pneumonectomy and later a thoracoplasty.

(Slide.) Last week I was presented with this patient. This 21-year-old man was in an automobile accident ten years ago and was treated in a small hospital in a neighboring town; he also recovered with prayer and oxygen. However, he now has a complete dextrocardia, apparently a complete block of the right main bronchus; the left upper lobe I think has herniated into the right chest, and we are presented with the problem of what we can do to rehabilitate him. He has pain, dyspnea, weakness on exertion, cannot work. I would like to ask Dr. Gebauer if he thinks at this late stage it is possible to restore the continuity of this bronchus and restore the function of the right lung. Would it be more sensible to do a pneumonectomy than a thoracoplasty?

Apparently fracture of the bronchus is a more frequent occurrence than we think. Probably most patients die very shortly from their injuries, but occasionally one might be saved if the condition were recognized and if the surgeon were bold enough to go in and repair it.

DR. JENS L. HANSEN, Copenhagen.—I have performed bronchial resection in a small series of cases. I should especially like to mention three cases in which bronchial carcinoma was located in the right upper lobe and extended to the main bronchus. Pneumonectomy was considered too risky; all the patients had emphysema and heart disease. An upper lobectomy would involve bronchial closure in malignant tissue. Combined with a resection of the main bronchus (about one-half to three-fourths of an inch) the tumor could be totally removed, according to frozen section histologic examination. The lower and middle lobes were mobilized by dissecting around the vessels and severing the pulmonary ligament. Hilar and mediastinal lymph nodes were removed. The azygos vein was resected lateral to the central portion of the main bronchus. Now the end-to-end anastomosis was easy to do. The two lumina were equalized by oblique cutting of the distal one. A pleural flap was sutured around the bronchial anastomosis. Aeration of the middle and lower lobes was obtained immediately.

One of the patients died three days postoperatively of heart failure, and one died eleven months after surgery, from metastases. In both cases autopsy showed that the anastomosis was sufficient. No local recurrence was disclosed. One patient is still living one year after operation.

Of course, this type of surgery in cases of bronchial carcinoma should be restricted to very selected cases. In our series of about 300 lung resections for carcinoma, only 1 per cent of the cases were suitable for combined upper lobectomy and bronchial resection.

DR. K. ALVIN MERENDINO, Seattle.—Dr. Gebauer is to be congratulated on the clinical contributions he has made to this problem. Many of the members of this Association have contributed to the problem experimentally. In the experimental laboratories of the University of Washington my associate, Dr. Lawrence B. Kiriluk, and I have performed almost 200 experimental operations on the dog. We have satisfied ourselves that such tracheo-bronchial reconstructive procedures are not only feasible but safe, further, that the bronchus may be transected in any plane and be assured of a satisfactory blood supply. Healing is not affected in any way. This is important in that either end or both ends can be "tailored" so that an isoproportional lumen is available for a proper anastomosis. On bronchospirometric studies in dogs it has been found that the lungs distal to tracheobronchial reconstructive procedures apparently respire in a normal fashion; also, once the lumen is established, stenosis does not occur up to a period of two years.

I would like to present certain material that we have available which closes the gap somewhat between the experimental problem and its sound clinical application.

(Slide.) These are the measurements between the coryna and the take-offs of the various bronchi and segments of the lung in 135 freshly autopsied cadavers. These spacial measurements are helpful in establishing what can and what cannot be done.

as the control of secondary infection incident to it was sure to become more difficult with the passage of weeks, I felt committed to attempt tracheobronchial reconstruction before control was lost, despite the incomplete healing of the tuberculous process.

With some comfort from the knowledge of Mr. Cleland's success in the face of residual activity, operation was undertaken ten days after tracheotomy. The procedure is depicted in Fig. 12. The distal line of excision of the right bronchus was across both the upper and the lower lobe bronchi, creating a rather large double-barreled structure. The proximal line of excision was at the coryna. The most severe tracheal stenosis extended upward 3 to 4 cm. from this level. The lateral tracheal wall was incised longitudinally in this area; some of it was extremely fleshy and edematous, and a narrow strip was excised from the anterior margin. The incised trachea was spread open and the distal right bronchus transported upward to fill the opening, its dimensions being quite adequate, when added to the circumference of the stenosed trachea, to provide a good tracheal lumen. A good airtight anastomosis was performed. There was some downward drag on the right hilum even after division of the pulmonary ligament. The long tracheotomy tube was replaced with a standard tube, and the postoperative course was without incident. Bronchoscopies seven days and three weeks after operation showed excellent early healing and good openings to both lobes. The short tracheotomy tube was removed after one week. The patient is now comfortably continuing a long period of rest and antimicrobial treatment.

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DISCUSSION

DR. JULIAN A. MOORE, Asheville, N. C.—Without having had any experience with anastomosing the bronchus, I would like to present a case of traumatic stricture, and maybe get some free advice concerning treatment. I have seen three traumatic strictures in the past twenty years which resulted from crushing wounds of the chest. One occurred in a young man who was injured in an automobile accident; he was treated in a small hospital by oxygen and prayer and recovered. There was complete stricture of the bronchus which resulted in complete shift of the mediastinum to the left with considerable symptoms. Colonel Keller did a thoracoplasty on that individual about twenty years ago and the patient has remained well since.

Two years ago I saw a young woman who had sustained multiple injuries in an automobile accident: fractures of the skull, the jaw, the clavicle, and one rib, with a hemothorax. She, too, got well with prayer and oxygen, and a resultant stricture of the right main bronchus resulted. After listening to the first presentation by Dr. Gebauer on this subject two years ago, I explored the chest hoping to be able to reconstruct the bronchus,

DR. WILLIAM M. TUTTLE, Detroit.—I have been most interested throughout the years in following Dr. Gebauer's experimental and clinical approach to the problem of bronchial anastomosis. We have been interested in this subject as you know for some time. Several years ago I reported in a discussion at this meeting my experiences with a patient on whom such a procedure was carried out. This was done in 1947, and I believe is the first instance in which such a procedure was performed on a patient. In the course of doing a revision lobectomy, which required the removal of the lingula and the superior division of the left lower lobe which had been left in the course of a snare lobectomy done in 1941, the upper lobe bronchus was injured to such an extent that it seemed (in view of our experimental work at that time) to be more feasible to remove the upper lobe and reanastomose it to the left main bronchus. The postoperative course was uneventful. The patient has subsequently undergone several broncho-scopies which reveal the anastomotic area to be normal and without stenosis. Subsequently, too, in the year 1950, a segmental resection was done of the posterior apical segment of the right upper lobe without incident on this same patient.

DR. WILLIAM A. HOPKINS, Atlanta.—After Dr. Gebauer's excellent report several years ago we became interested in the use of dermal grafts and methods of closing defects in the bronchi. I wish to report briefly four cases in which this method has been used successfully: to enlarge the bronchus in one case, and to close a defect in the trachea and bronchus in three other cases.

The first case involved an 11-year-old boy who had a right bronchial stricture at the level of the right upper lobe. This followed the aspiration of a staple at the age of 2 years. It remained within the bronchial tree for a year, then was removed, and a stricture developed.

(Movie.) This shows fluoroscopic study of the chest with cinefluorography. Note shift of the mediastinum to the right side with inspiration. At the time of surgery a Gebauer dermal graft was inserted at the level of the right upper lobe. The entire right lung was normal except for underdevelopment. The patient is now doing well, two years after surgery.

The next two cases encountered were malignancy of the right upper lobe in which there was an abnormal high take-off of the right upper lobe bronchus in one case, much higher than normal. In the second case there was direct invasion of the coryna. The right portion of trachea, the coryna, and the medial side of the left main-stem bronchus were resected following pneumoectomy. The defect was replaced by a Gebauer type of graft. Both cases did very satisfactorily postoperatively and have recovered. In one case a fistula has developed. In neither case was there evidence of metastasis to the lymph nodes. The local extension and the relationship to the bronchi made this form of resection necessary.

Our fourth case was a 4-year-old child who had a large simple cyst of the posterior portion of the lower end of the trachea. On excision of the cyst it was found that the cyst wall was the posterior wall of the trachea and it was replaced by dermal graft. Surgery was completed eight months ago and to date the child is doing very satisfactorily.

DR. ALFRED GOLDMAN, Beverly Hills.—One year ago in THE JOURNAL OF THORACIC SURGERY, we reported four cases of transpleural bronchotomy for bronchial tumors of the adenomatous group, and I would like at this time to report a follow-up on those cases. The oldest case involved a tumor of the left stem bronchus which was removed with left lower lobectomy. This patient is now about eight years postoperative. She had a bronchial adenoma and now she has no signs of recurrence. Two patients were operated upon in 1949; the first had a tumor in the left stem bronchus, and the entire wall of the bronchus was not removed but an incision was made and a pedicle tumor removed with cauterization of its base. This patient is alive without recurrence or bronchial stenosis after four years. The other case concerned a patient with adenoma of the right stem bronchus located on the medial wall of the first ring below the coryna; we did a resection of the entire wall and resutured. This patient is alive without signs of recurrence after four years. We feel that this group of adenomatous tumors is amenable to local excision in selected cases.

(Slide.) In a smaller study of 55 freshly autopsied cadavers, the luminal diameters of the areas which might be utilized in tracheobronchial reconstructive procedures are shown.

I am somewhat hesitant to present a single case report. However, in view of Dr. Gebauer's reference to an Australian colleague who recently treated a bronchial adenoma by bronchial reconstruction, and because no single individual may have a large experience with this problem, and in the hope that others will attempt it, I would like to report a case of bronchial adenoma treated by a reconstructive procedure.

(Slide.) This is a 64-year-old white man who presented himself with progressive dyspnea, hemoptysis, and lower left chest pain. This is a typically emphysematous chest.

(Slide.) This is the lesion which was in the lower lobe. On bronchoscopy, the bronchoscopist thought that the lesion was too close to the left upper lobe take-off to do a left lower lobectomy.

(Slide.) The patient was seen by our cardiorespiratory study group who felt that he could be explored but that only the most minimal type of excisional surgery should be considered. This is a schematic presentation of the site of the bronchial adenoma, and the A and B lines indicate the line of transection of the left upper lobe bronchus and the left main bronchus.

(Slide.) This is the reconstructive procedure that was done, an anastomosis end-to-end of the left upper lobe bronchus to the left main bronchus. The inset indicates the excised specimen including the left lower lobe, a portion of the left upper bronchus, and a portion of the left main bronchus.

(Slide.) This gives an idea of how much additional bronchus may be resected by such a procedure. By measurement, an additional 4 cm. of proximal bronchus was excised with the specimen which otherwise would not have been obtainable. I think it is evident also from our initial schematic drawings, which were to scale, that a great variety of reconstructive maneuvers can be carried out and this represents one variant.

(Slide.) This is a view of the tumor.

(Slide.) This is an x-ray picture taken eight months postoperatively. On differential bronchspirometry at approximately this same period after surgery, it was found that the left lung (left upper lobe) accounted for 38 per cent oxygen consumption and 47 per cent ventilation. Now, more than a year later, this patient remains a garrulous old man who now states that he can talk continuously without having to stop for breath as was the case preoperatively.

DR. FREDERICK G. KERGIN, Toronto.—We also have been interested in Dr. Gebauer's work and have used his dermal graft reinforced by wire on several occasions including one time for adenoma in a young woman, a situation very similar to the case shown of Mr. Officer Brown. In this case we were able to resect the adenoma and use a graft and save the lung. It was a great satisfaction, and so far the lung is functioning very effectively. We had one other case recently, similar to the case Dr. Moore spoke about. A young man of 22 who had, thirteen weeks previously, a crushing injury to the chest which was followed by hemoptysis and very severe emphysema. In Canada we also use prayer and oxygen, and he survived. He came to us with atelectasis of the middle lobe.

(Slide.) This shows an obstruction of the right main bronchus near its origin. From the history we could recognize that this patient had a fracture of the right main bronchus near its origin, and this diagnosis was confirmed by bronchoscopy.

(Slide.) At operation we found a situation like this: Apparently the right main bronchus had been torn from the trachea. There was a tremendous inflammatory reaction which rendered dissection difficult, and there was almost no lumen. We were able to resect the damaged portion of the bronchus as shown in the second diagram, leaving a rather ragged defect here and a similar ragged defect in the bronchus. These were brought together as shown in the third diagram. This operation was performed only eight days before I left Toronto and at that time the patient was well and showed re-expansion of the right lung, and no leakage of air.

I should like to say that I enjoyed Dr. Gebauer's presentation very much.

PULMONARY DISTENTION AS SEEN IN THE LORDOTIC ROENTGENOGRAM

JOSEPH GORDON, M.D.,* AND W. BERKELEY ZINN, M.D.** (BY INVITATION)
RAY BROOK, N. Y.

THE lordotic roentgenogram has been used to visualize better the pulmonary apices with the clavicles out of the lung fields, as first reported in this country by Baum and Black.¹ In the lordotic film, the point of apposition of the two lungs in the anterior mediastinum is indicated by a plainly visible linear radiopacity (Figs. 1 and 2). This line is apparently due to the four layers of pleura (two parietal and two visceral) between the air-containing lung immediately adjacent on either side. This is more strikingly illustrated in Figs. 3 to 5 where a right-sided hydropneumothorax can be seen crossing into the left hemithorax. The linear density noted in the lordotic film is thereby identified as pleural displacement from right into left hemithorax.

When the heart and trachea are deviated toward one side, it is obvious that the lung on the other side is distended to an unusual degree. When these structures appear in normal or nearly normal position, considerable overdistention of one lung may occur as a result of herniation of a portion of one lung, usually through the anterior mediastinum into the opposite hemithorax.

It is considered that an anterior mediastinal lung hernia exists only when the anterior portion of one lung extends beyond the trachea into the opposite hemithorax. If the lung does not extend beyond the trachea, it is not considered that a hernia is present. With either a mediastinal lung hernia or mediastinal displacement, one lung (or a portion of it) must be distended to an unusual degree. When all of the mediastinal structures are displaced, the situation is obvious. The true situation may not be obvious, however, when the readily visible mediastinal structures (heart and trachea) lie in normal position or are only slightly displaced. In these circumstances, it is fairly common in our experience to have a sizable anterior mediastinal lung hernia which is demonstrated best or only in a lordotic film.

TECHNIQUE

The Bucky diaphragm is routinely employed by us in taking lordotic films. The patient stands with the back toward the cassette changer or the table in the vertical position if the table Bucky is used. One short step is taken away from the cassette changer and the patient leans back, resting the uppermost dorsal part of the chest against the cassette changer. The back should be well arched, the thorax at an angle of about 45 degrees to the cassette.

From the Ray Brook State Tuberculosis Hospital.

Read (by title) at the Thirty-second Annual Meeting of The American Association for Thoracic Surgery, Dallas, Texas, May 8-10, 1952.

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**Supervising Roentgenologist, Ray Brook State Tuberculosis Hospital.

DR. ROSS ROBERTSON, Vancouver.—I would like to add two cases treated by Dr. Gebauer's technique, and also to ask him a question about the technical management.

The first case concerned a woman, aged 27 years, who had an adenoma in the right main bronchus just at the orifice of the upper lobe bronchus, which caused an obstructive emphysema of the right lung. In this case the right upper lobe was resected along with a cuff of the main-stem bronchus, and the continuation of the main-stem bronchus was anastomosed to the trachea at the coryna. The second patient was a man, aged 72 years, with a well-differentiated squamous-cell carcinoma completely obstructing the right upper lobe bronchus and extending along the mucosa of the trachea on the outer surface for a distance of about 2 cm. In this case the medial surface of the right main-stem bronchus was preserved as a flap and was turned up to cover the defect in the trachea which had been removed along with the right lung. Pathologic examination showed that the tumor did not even penetrate the muscle coat of the bronchus, and that there were no glands involved. In both these cases the postoperative convalescence was remarkably smooth and I certainly would like to recommend the technique.

I would like to ask Dr. Gebauer whether he makes a point of preserving the bronchial arteries to the remaining bronchi.

DR. GEBAUER (Closing).—I am pleased that dermal grafts and bronchial resections are being successfully done. I thank Drs. Moore, Hansen, Hopkins, Merendino, Kergin, Tuttle, Goldman, and Robertson.

Bronchostenosis resulting from chest trauma is unquestionably more common, as Dr. Moore mentioned, than we previously imagined. I believe early bronchoscopy and consequently thoracotomy are frequently neglected in severe chest injuries.

I am glad that Dr. Tuttle's patient with upper lobe anastomosis is still well after five years. Accidental division of bronchi is more common than indicated by the literature, and it should not necessarily call for excision of the part supplied by the divided bronchus. I feel that this has been the case quite frequently in the past.

The use of dermal grafts and plastic bronchial procedures to extend the limit of resection for carcinoma is, perhaps, a slight improvement of a therapeutic measure that leaves much to be desired. Unquestionably there is ample room for improvement in the surgical treatment of lung cancer.

Dr. Hopkins' movie was excellent and I am pleased with his successful cases.

The salvage of good lung tissue, especially in older people, as illustrated by Dr. Merendino, is most creditable. His case, as well as Dr. Goldman's experience, indicates that many bronchial adenomas can be successfully treated by bronchial excision.

The use of a local or "wedge" excision, as reported by Dr. Kergin, to restore a bronchial lumen, will be most often applicable to deformities involving the right upper and proximal main bronchi. The application of a simple plastic procedure can be most gratifying.

In answer to Dr. Robertson, we try to preserve the bronchial arteries but do not particularly avoid their division if we need room. Especially in doing a dermal graft, we do avoid peribronchial dissection as much as possible.

the diseased part contracts, it moves posteromedially toward the paravertebral gutter. Rotation similarly occurs in the presence of pulmonary collapse by pneumothorax and thoracoplasty. This is evidenced at bronchoscopy by noting rotation of the tracheal carina and displacement of certain of the bronchial openings in a clockwise or counterclockwise direction, depending upon the side toward which the rotation occurs.

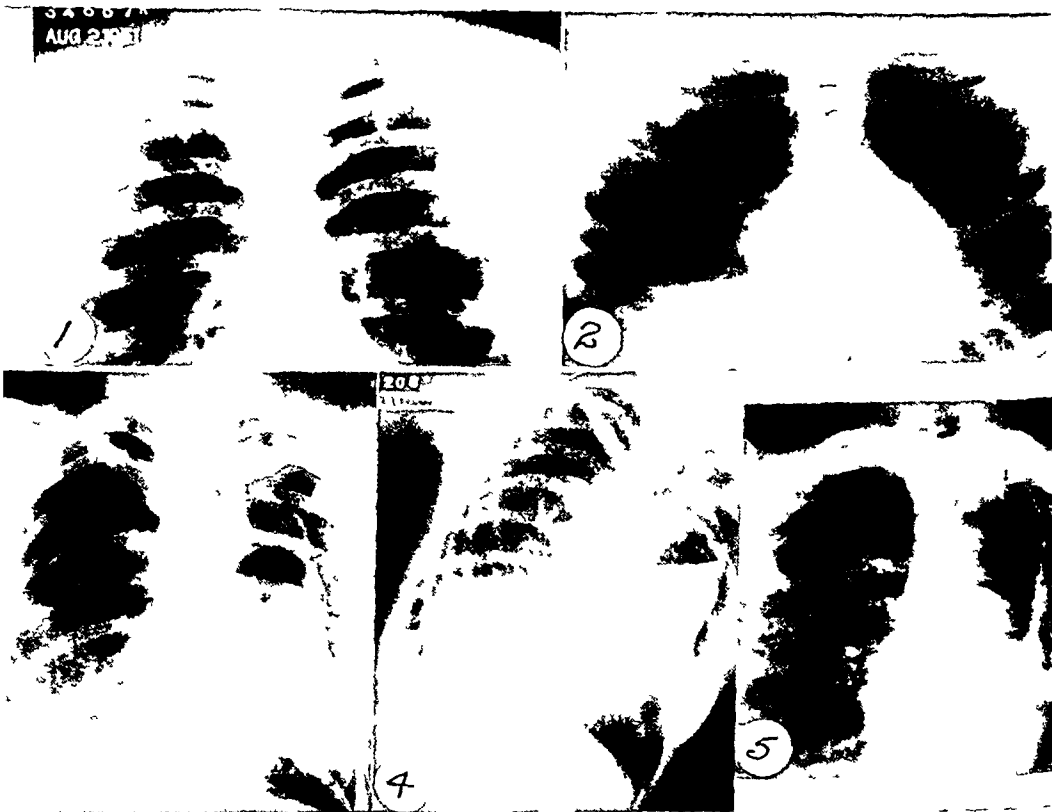
The roentgenogram may show the position of the mediastinal structures to be normal or deviated to one or the other side. Rotation may not be recognized. Where the fissure lines can be detected in the posteroanterior or lateral films, they are helpful in discerning areas of lung distention. The lordotic film, however, is most helpful and often shows distention of a part of the lung (lung hernia) over to one or the other side of the midline. Where a considerable amount of disease in the upper lobe produces contraction, there results displacement of the opposite lung.

Pulmonary compensation by such displacement is often observed at post-mortem examination after removal of the breast plate. When one lung is greatly shrunk, the opposite lung may be distended into the hemithorax containing the shrunk lung. Moreover, in open chest surgery for tuberculosis, at times a despression or protrusion of the pleural membranes along the anterior mediastinum may be noted. Evidence of compensation by distention of the lung is best seen in cases of abandoned pneumothorax. In some cases, where little or no hernia is noted before pneumothorax treatment, a rather striking change is seen after, especially where the re-expansion is complete. There is other evidence of decrease in volume of the treated lung; the mediastinum is seen to shift to the diseased side and the other factors of compensatory change (flattening of the chest wall, elevation of the diaphragm, and limited motion) may also be observed. When lordotic roentgenograms are taken, a localized area of distention of the lung is seen, not generally detected in the conventional film.

The lordotic film will demonstrate small areas of pulmonary distention (Fig. 2), whereas bronchspirometry cannot localize distention to lobes and can only reveal relatively large changes in lung volume. The distention of the contralateral lung toward the diseased side may be seen in varying degrees, from a slight amount of displacement which can just be seen within the air column of the tracheal shadow, to extensive shift of a portion of the lung well into the opposite side (true herniation). The degree to which pulmonary displacement may occur is dependent upon a number of factors which will be considered later. However, the chief of these is reduction of lung volume secondary to disease or removal of lung tissue.

A relatively small amount of lung involvement, as seen in the conventional posteroanterior roentgenogram, may be accompanied by unexpected displacement of the uninvolved lung toward the side of the disease, as demonstrated only in the lordotic film. This finding would suggest that the extent of lung damage indicated in the regular roentgenogram may not be accurate. In the absence of serial films, it is reasonable to assume that more extensive disease was previously present and clearing occurred without restitution of the

This will vary somewhat with the patient's build, the object being to project the clavicles completely out of the lung fields. The shoulders should then be hunched forward and elevated as much as possible. The x-ray tube focal spot is positioned about one inch below the level of the xiphoid cartilage. An 11 by 14 inch film is used with the long dimension horizontal. Focal spot film distance is 48 inches. Exposure factors: 200 Ma; 0.1 second; usual KVP 90 to 94 depending on the size of the patient, with extremes of 86 KVP (for a very small person) and 98 KVP (for a very large person). By this technique, evidence of herniation secondary to change in size of lung will be best seen.



Case 1

Fig 1—Posteroanterior roentgenogram showing shadow of minimal disease in right second anterior interspace

Fig 2—Lordotic roentgenogram showing shadow of lesion to better advantage. Arrows outline border of left lung shadow seen crossing that of tracheal air column indicating beginning displacement left to right hemithorax.

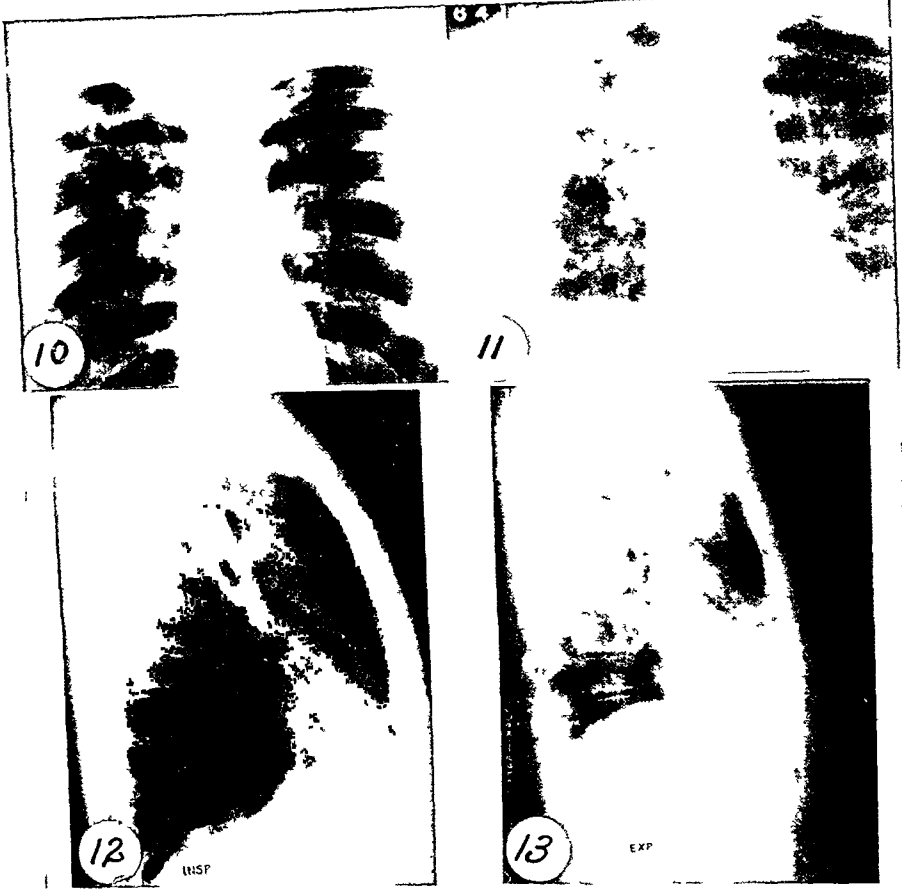
Case 2

Fig 3—Posteroanterior roentgenogram showing bilateral pneumothorax with bilateral fluid. The arrows outline a mediastinal displacement of right hydropneumothorax into left chest.

Fig 4—Roentgenogram taken in tilt position further verifies the above findings.

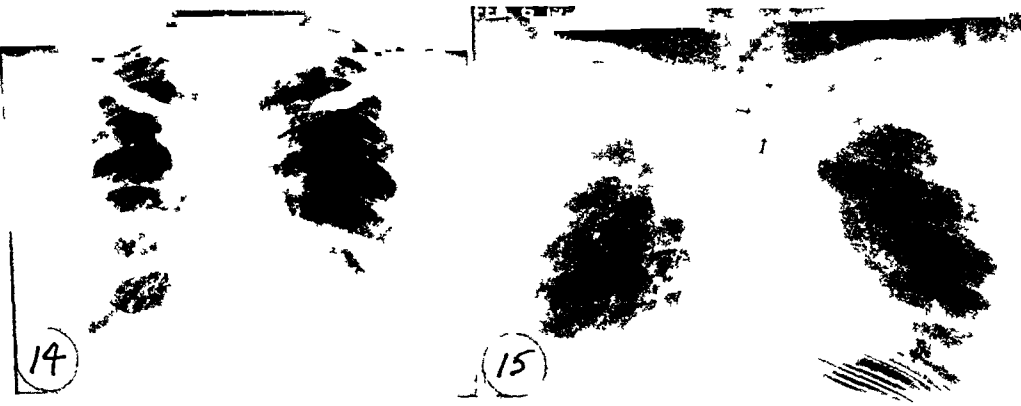
Fig 5—Lordotic roentgenogram showing displacement or herniation of mediastinal pleura from right into left hemithorax.

The loss of lung volume may be the result of parenchymal disease, bronchial disease, resection of lung tissue, or limitation of expansion by pleurogenic factors, or any combination of these. It is well known that tuberculosis is most often located in the apical and posterior portions of lobes. Commonly, when



Case 4

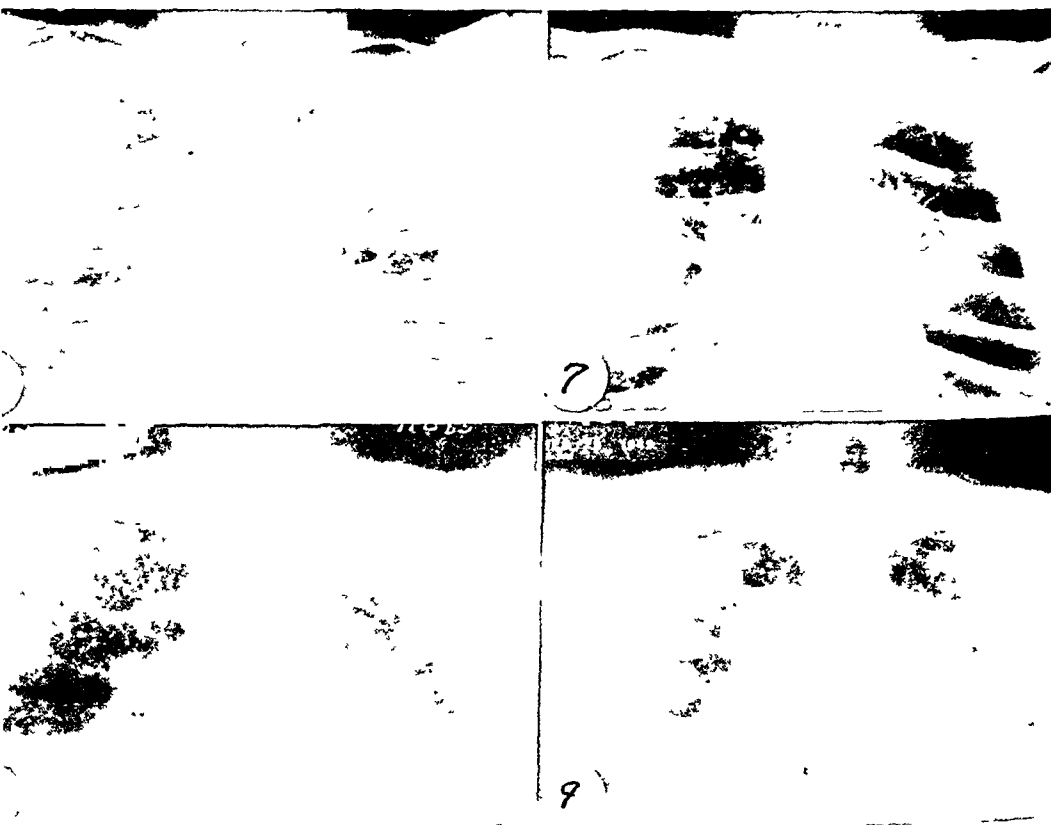
Fig 10—Posteroanterior roentgenogram showing giant sized cavitary shadow with surrounding densities. Note absence of tracheal deviation despite extensive pulmonary disease.
 Fig 11—Lordotic roentgenogram showing same shadows to better advantage. Note absence of any contralateral pulmonary displacement.
 Figs 12 and 13—Right lateral roentgenograms taken in both inspiration and expiration to show localized obstruction (failure to deflate) of right upper lobe accounting for absence of shift and displacement.



Case 5

Fig 14—Posteroanterior roentgenogram of patient with bilateral pulmonary disease. Bilateral pleurisy.
 Fig 15—Lateral view showing very limited herniation. This is in presence of marked restrict.

lung to normal. Reduction in lung volume, therefore, made a demand for space filling, resulting in the yielding of the weak anterior mediastinum, permitting herniation of the opposite lung. In the presence of bilateral disease, displacement toward one side would indicate which lung had the greater reduction of lung volume. In bilateral re-expanded pneumothorax, the degree and side of displacement would indicate which lung re-expanded the better or had the lesser extent of lung damage (Figs. 6 to 9).



Case 3

Fig. 6.—Lordotic roentgenogram showing bilateral pneumothorax and no visible "hernia"

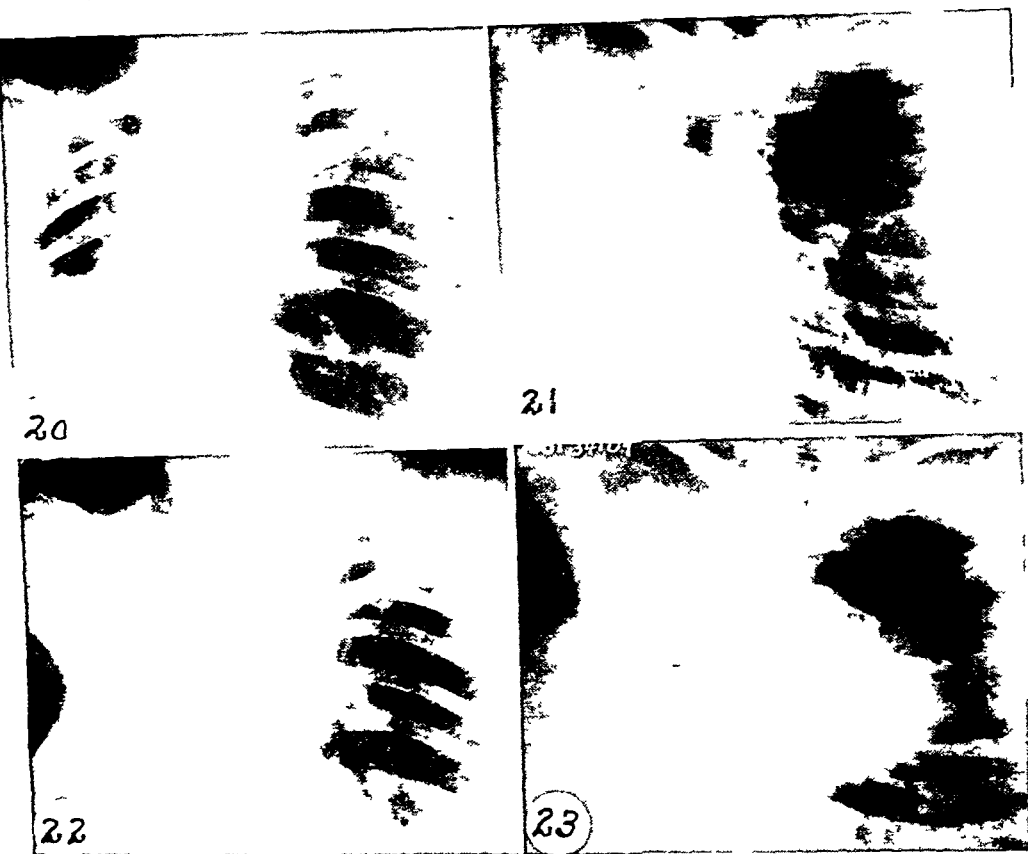
Fig. 7.—Lordotic roentgenogram after re-expansion of right pneumothorax, showing "hernial" displacement from left to right.

Fig. 8.—Lordotic roentgenogram showing "hernial" displacement now right to left as pneumothorax on the left is being let up

Fig. 9.—Lordotic roentgenogram after complete re-expansion on both sides "Hernial" displacement remains to the left

The degree of pulmonary displacement is not always predictable from a casual review of earlier films, as a number of factors are concerned. Repeated local spreads of disease accompanied by clearing may have caused greater change in the surrounding lung than suspected. A point could be reached where irreversible emphysema was produced in the segment of lung containing

exerted here is chiefly hydrostatic but, in reality, there may be a negative intrapleural pressure exerting its effect upon the mediastinum. Shift toward the fluid side may readily occur and result in contralateral pulmonary displacement, despite the pressure of the fluid (Figs 16 and 17).



Case 8

Fig 20—Posteroanterior roentgenogram showing abnormal shadows in lower lung field chiefly and deviation of tracheal shadow

Fig 21—Lordotic roentgenogram showing pulmonary displacement of left lung into right hemithorax

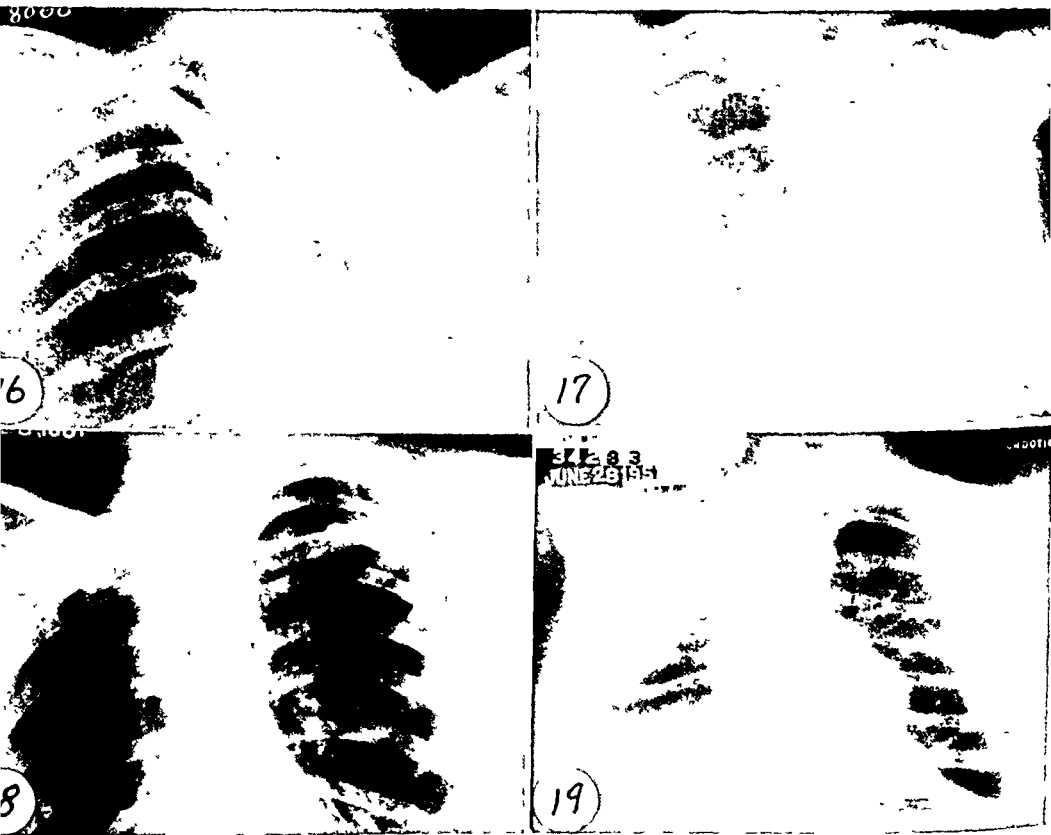
Fig 22—Posteroanterior roentgenogram following pneumonectomy for bronchial and pulmonary disease followed in one month by thoracoplasty with removal of first rib

Fig 23—Lordotic roentgenogram showing reduction in size of herniation despite pneumonectomy but with addition of thoracoplasty.

A not too dissimilar condition is noted in cases where thoracoplasty is done following resection, leaving behind the first rib. Here, too, is noted a space-filling shift of the contralateral lung, seen best in the lordotic film (Figs 18 and 19). In contrast to this, even after pneumonectomy, if the thoracoplasty includes the removal of the first rib, this tendency to distention may be greatly limited or prevented (Figs 20 to 23). However, when there is pre-existing pulmonary displacement, it is not always reducible by thoracoplasty (Figs. 24 to 29). Experience has shown that even where the entire first and second ribs,

the visible area of disease. Where obstructive emphysema is present, decrease of lung volume is not very marked and there may be little or no herniation even in the presence of extensive pulmonary disease (Figs. 10 to 13).

A similar situation may be present when bilateral effusion (Figs. 14 and 15) or unilateral effusion on the side opposite that containing the greater amount of disease has caused limited mobility of the lung. In other instances there may have been antecedent bronchitis and emphysema, asthma, or other pulmonary disease, associated with decrease in elasticity of the lung. Any of



Case 6

Fig. 16.—Posteroanterior roentgenogram of case of abandoned pneumothorax with fluid replacement. There is collapse of underlying lung and tracheal shadow is shifted to left.

Fig. 17.—Lordotic roentgenogram showing pulmonary displacement of right lung into left hemithorax. Though there is a filled left hemithorax, the conditions are hypotensive, permitting of shift.

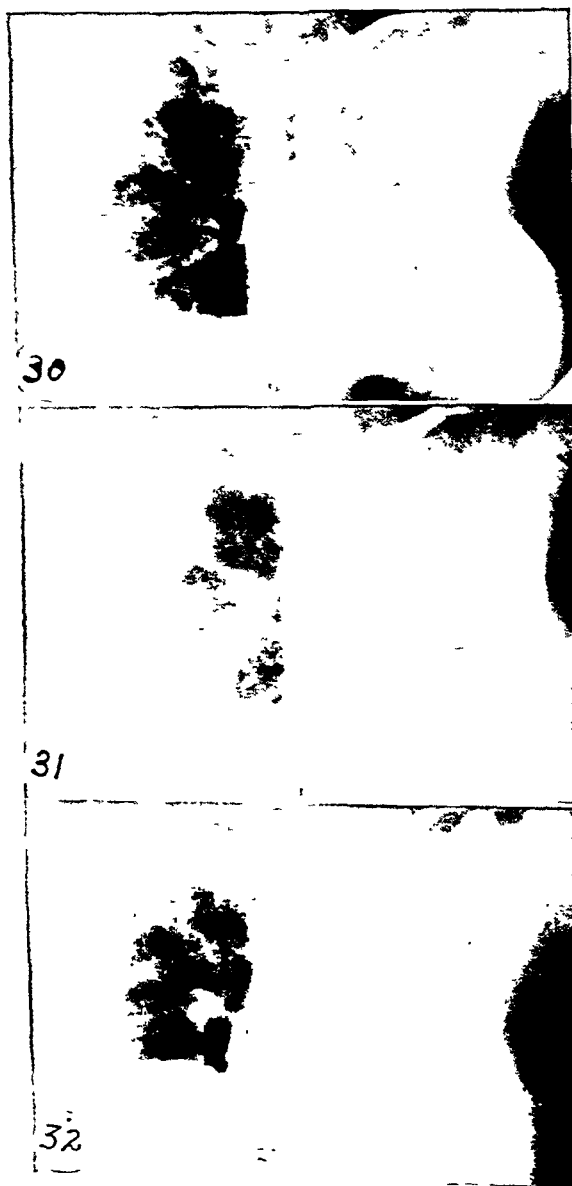
Case 7

Fig. 18.—Posteroanterior roentgenogram of patient who had right upper lobectomy with limited thoracoplasty leaving first rib in place.

Fig. 19.—Lordotic roentgenogram showing the pulmonary displacement of left lung toward right, crossing a part of the deviated tracheal shadow.

these above factors would modify the forces causing the displacement. On the other hand, an abandoned pneumothorax may have been allowed to fill with fluid for the purpose of "holding down" the collapsed lung. The pressure

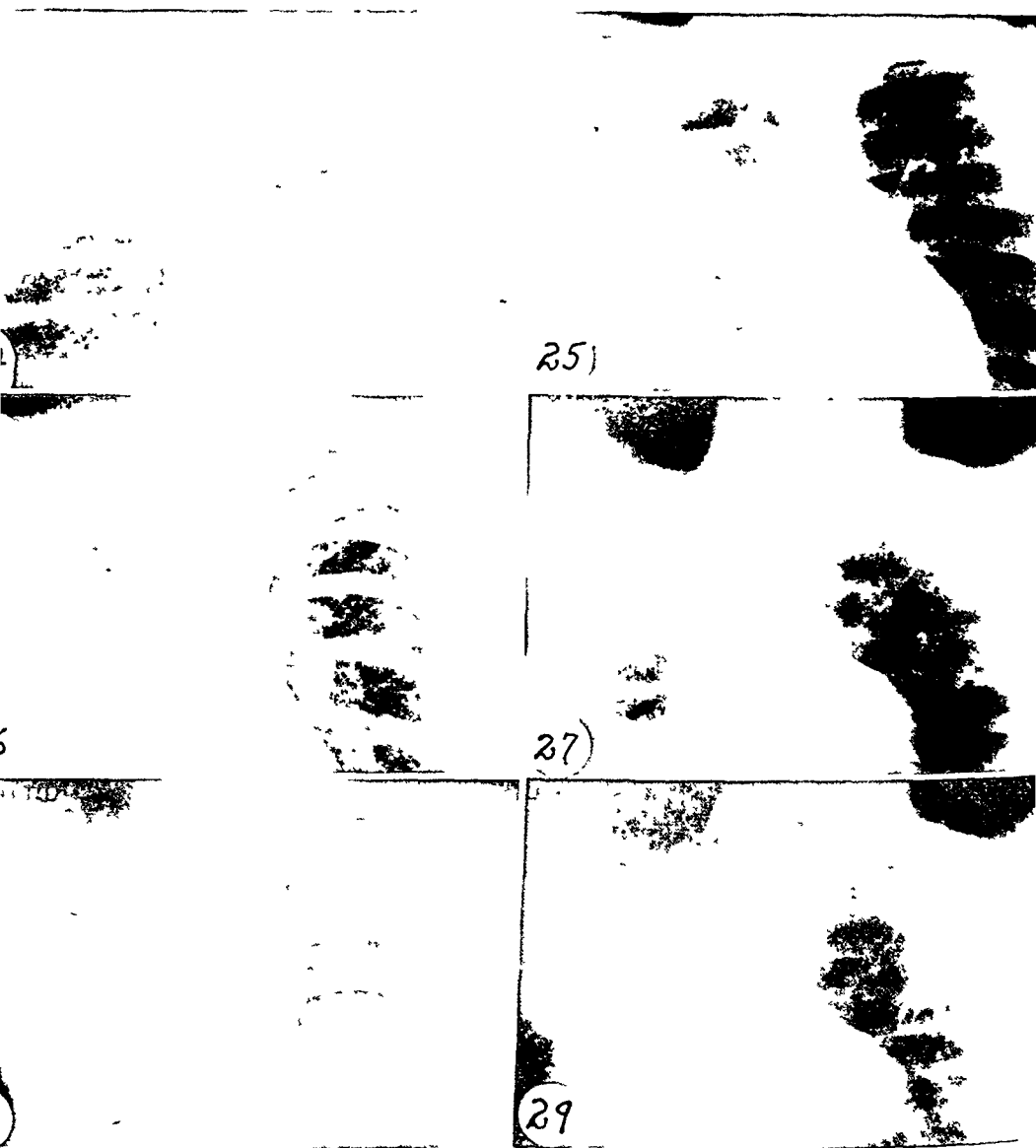
In other cases, there is reduction in the size of the hernia or it may be satisfactorily corrected (Figs. 30 to 32). On occasion, there may be further increase in the amount of pulmonary displacement following thoracoplasty. The latter apparently results from the further collapse with posterolateral rotation



Case 10

FIG. 30.—Lordotic roentgenogram before thoracoplasty showing herniation of right lung to 1-ft hemithorax as well as fluid level in large cavity.

Figs. 31 and 32.—Lordotic roentgenograms showing progressive decrease in size of hernia following first and second stages of conventional thoracoplasty.

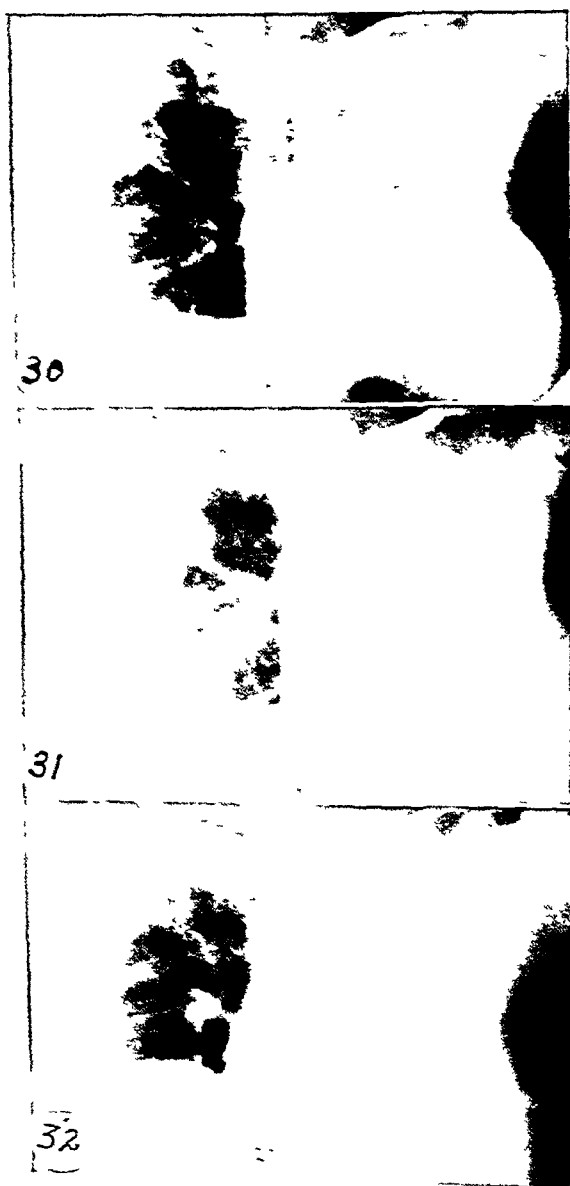


Case 9

- Fig. 24 —Lordotic roentgenogram showing pulmonary shadows and absence of herniation
 Fig. 25 —Lordotic roentgenogram after pneumothorax again in the absence of herniation
 Fig. 26 —Posteroanterior roentgenogram following re-expansion of unsuccessful pneumothorax showing mediastinal shift to the right.
 Fig. 27 —Lordotic roentgenogram showing marked herniation
 Fig. 28 —Posteroanterior roentgenogram following thoracoplasty with good anatomic collapse
 Fig. 29 —Lordotic roentgenogram showing persistence of pulmonary displacement

including the cartilage to the sternum, are removed in a preliminary anterior operation, the hernia may persist. With the thoracoplasty completed posteriorly, the mediastinum may not be returned to the normal position and the distention not corrected.

In other cases, there is reduction in the size of the hernia or it may be satisfactorily corrected (Figs. 30 to 32). On occasion, there may be further increase in the amount of pulmonary displacement following thoracoplasty. The latter apparently results from the further collapse with posterolateral rotation



Case 10

Fig. 30.—Lordotic roentgenogram before thoracoplasty showing herniation of right lung to left hemithorax as well as fluid level in large cavity.

Figs. 31 and 32.—Lordotic roentgenograms showing progressive decrease in size of hernia following first and second stages of conventional thoracoplasty.

of the underlying diseased lung as healing organization takes place. Such an increase in pulmonary distention as seen by lordotic roentgenogram helps to explain why in some cases the late effects of thoracoplasty are associated with further loss of pulmonary function, in addition to the scoliosis reported by others.²



Case 11

Fig. 33.—Lordotic roentgenogram showing large hernial displacement of left lung into right hemithorax in inspiration by the standard technique

Fig. 34.—Same during expiration showing marked reduction in size of hernia.

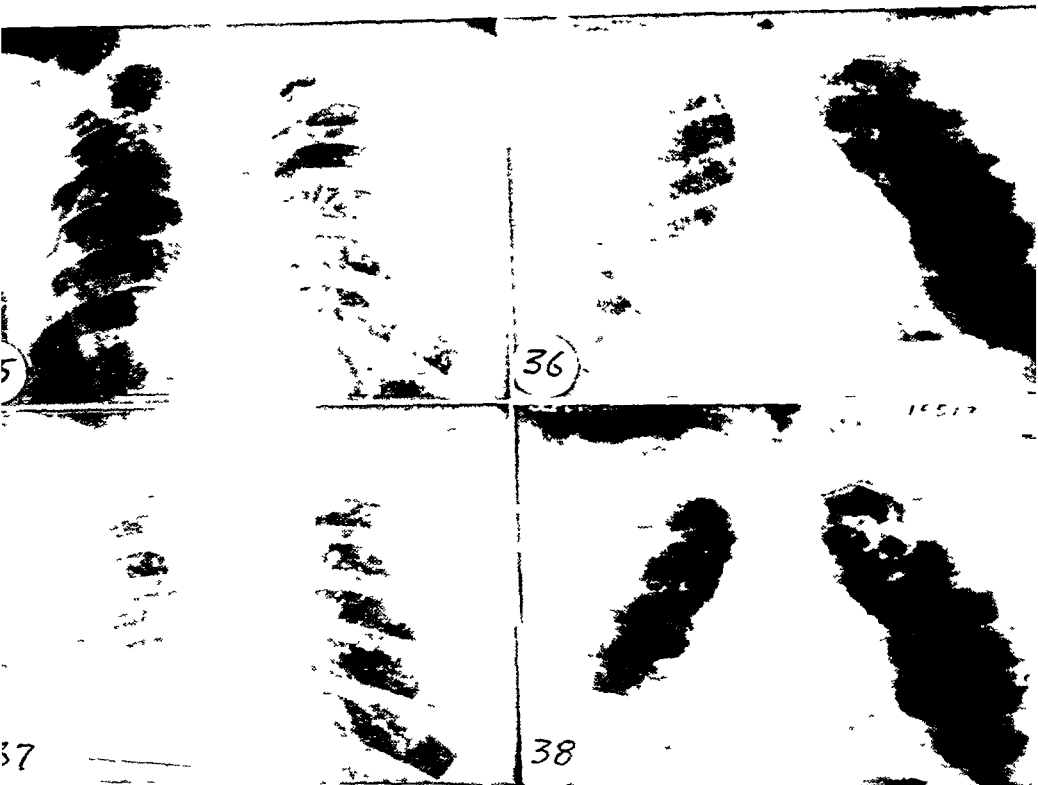
Where thoracoplasty is done some time before pneumonectomy or before complete abandonment of pneumothorax, this displacement may be greatly limited or perhaps prevented. It has been reported by others³ that greatly delayed thoracoplasty after pneumonectomy, because of pulmonary overdistention, fails to improve function. The lordotic film, showing persistence of herniation following thoracoplasty, indicates that the overdistention was not corrected. A clue as to the expected successful replacement of the distended lung may be had by comparing the lordotic roentgenograms taken in inspiration and expiration (Figs. 33 and 34). In some instances, these herniated portions of the lung may become smaller, others disappear from view, while still others remain unchanged in expiration. Those remaining unchanged behave very much like an area of localized obstructive emphysema, resisting collapse.

A further observation noted in this study was contralateral breakdown in some cases after re-expansion of a successful pneumothorax (Figs. 35 to 38). The material did not lend itself to statistical analysis, but a strong impression was gained that two factors were common. There was usually a previous small focus of disease in the lung opposite to that treated by pneumothorax and, furthermore, the breakdown, as seen in the lordotic film, was at the same level as the herniated portion of the lung. A similar set of circumstances was noted, as well, in thoracoplasty cases (Figs. 39 to 42).

There were cases that had contralateral foci with herniation of lung before the thoracoplasty was done. At a later date it was noted that (1) the hernia persisted, and (2) the contralateral breakdown was at the same level. A correla-

tion between pulmonary overdistention and breakdown of tuberculous foci has been under study for some time, but the evidence for cause-and-effect relationship is still inconclusive.

It has been noted also in the review of this material that not only is thoracoplasty not necessarily a corrective measure, but the displacement persists in the presence of phrenic nerve paralysis and of pneumoperitoneum. Plombage measures, on the other hand, may be seen effectively to correct the displacement.



Case 12

FIG. 35.—Posteroanterior roentgenogram showing pneumothorax on right.

FIG. 36.—Lordotic roentgenogram showing absence of displacement but showing minimal shadows in left upper lung field.

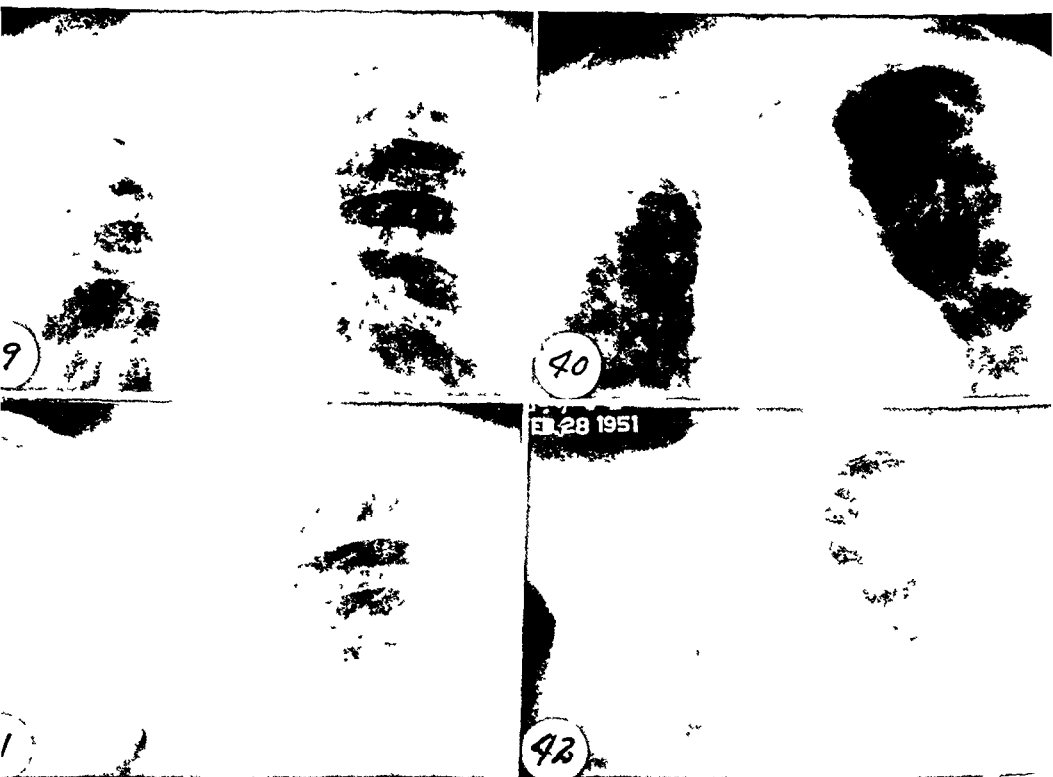
FIG. 37.—Posteroanterior roentgenogram after re-expansion of presumably successful pneumothorax on the right, but new shadow appeared on the left.

FIG. 38.—Lordotic roentgenogram showing to better advantage the annular shadow on the left directly opposite to the area of pulmonary displacement of left lung into right hemithorax.

This was seen in cases of extrapleural pneumothorax especially, since the pressures are usually kept on the positive side in both phases of respiration. Here, it is not unlike intrapleural air in that where there is a pre-existing displacement of the lung toward the side for which pneumothorax is to be given, the hernia is effectively reduced.

It is not intended to recommend plombage as a better form of collapse treatment. It can be said, however, that replacement of distended contralateral

lung is another reason for plombage in addition to its use to attempt to compress a lung that resists collapse by other means. This goes as well for the use of prosthesis in certain pneumonectomies instead of doing late thoracoplasty. The limitation of distention of the remaining lung is more effectively controlled by space-filling material.



Case 13

Fig 39—Posteroanterior roentgenogram before thoracoplasty showing shadow of moderate disease on the right with tracheal deviation and minimal shadow on the left

Fig 40—Lordotic roentgenogram showing herniation present of left lung into right hemithorax

Fig 41—Posteroanterior roentgenogram following thoracoplasty showing increase of shadow on left

Fig 42—Lordotic roentgenogram showing persistence of pulmonary displacement and development of annular shadow at site of previous focus

The pattern of compensatory dilatation of the lung is not known. It is not clear whether all of the remaining uninvolved tissue contributes to a degree to the distention, or whether immediately contiguous areas play the predominant role. It is possible to consider that the lung may have areas of different elasticity, inasmuch as about the root, in the apex and at the spine movement is restricted, and so also may be expansibility.

Microscopic examinations of pathologic tissue reveal that in the region of a tuberculous or other nodule the immediately surrounding alveoli are enlarged in contrast to the more distant normal sized air sacs. In examining

large portions of lung, one sees in addition to the characteristic areas of disease, some distended alveoli, others collapsed, and still others of comparatively normal size. The elastic property of the lung has been recognized and its ability to fill space in the thorax is particularly exemplified following pneumonectomy. Under other altered physiologic conditions, one may note collapse of lung tissue or inability of emptying as in emphysema. This latter may be secondary to (a) loss of elasticity or (b) bronchial obstruction. It is also known that both in the human being and in the experimental animal, emphysema is more commonly seen in the peripheral portions of the lung. This is more striking where blebs are noted under the visceral pleura.

It has been seen that a segment of lobe or an entire lobe may be lost by disease or resection without significantly altering measurable pulmonary function. The difference between compensatory dilatation and pathologic or so-called "irreversible emphysema" is a subject of debate between physiologist and pathologist. It is possible, however, to demonstrate localized regions of trapping of air by roentgen means and thereby conclude that functional alterations must likewise be present. It is tempting to suggest that a portion of the lung may undergo distention selectively and thereby permit the remaining lung to function normally within certain limits.

On the basis of these studies, the use of the lordotic roentgenogram has been extended. It is useful for checking on the re-expansion of pneumothorax (intrapleural and extrapleural). While shift of the mediastinum is easily recognized, contralateral pulmonary displacement may be seen to a greater degree in the lordotic roentgenogram or may be seen in the absence of tracheal shift. These findings have been given broader application from a surgical standpoint as well. The question as to when or if a space-reducing thoracoplasty should be done following resection or decortication remains a matter of personal preference for various reasons.

Here, in the lordotic roentgenogram, is some evidence regarding ipsilateral expansion and contralateral overexpansion which may serve in a general way as a yardstick. Following pulmonary resection of a lobe or less, the post-operative roentgenograms taken from three to four weeks after surgery are used in determining whether or not a space-reducing thoracoplasty will be performed. Should contralateral pulmonary displacement develop or exceed pre-existing change, the operation is generally done. In the presence of a small contralateral lesion for which bilateral resection is not planned, greater weight is given in favor of doing the thoracoplasty. In cases of decortication with or without parenchymal resection, the same pattern is generally applied. The development of or increase in size of a pre-existing contralateral lung hernia is suggestive evidence that re-expansion of the decorticated lung is limited. A thoracoplasty is therefore done to contain the re-expanded lung within its boundaries of expansion. This is to be preferred to overexpansion for space filling by emphysema, with possible reduction in function rather than improvement. It seems entirely possible, also, to use these clues of behavior of pulmonary distention in deciding about a preliminary thoracoplasty to decortication and/or lung resection.

SUMMARY

1. The lordotic roentgenogram reveals evidence of anterior mediastinal lung herniation, indicating pulmonary distention which may not be seen or suspected in other roentgenograms.

2. Contralateral pulmonary distention results from loss of lung volume secondary to pleural, bronchial, or parenchymal factors, or following resection.

3. Changes in lung size noted prior to surgery may be seen to persist following operation, as in thoracoplasty.

4. Exacerbation of parenchymal disease has been associated with pulmonary overdistention. This finding is believed to warrant further study.

5. The lordotic roentgenogram serves as a guide in assessing re-expansion of the lung following pneumothorax or resection and it is used to indicate when thoracoplasty might be added to advantage.

The radiographic illustrations were prepared by Anna M. Sanlow, Senior X-ray Technician, Ray Brook State Tuberculosis Hospital, Ray Brook, N. Y.

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EXPERIMENTAL LUNG TRANSPLANTATION

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THE exchange of a normal for a diseased organ has long been an appealing idea. Many attempts at homologous transplantation of various tissues and organs have been made, and, with the exception of an occasional successful "take" in skin grafts from an identical twin, all have ended in failure.¹ However, following the report of Juvenelle and his associates,² concerning successful autogenous reimplantation of a lung in a dog, we were stimulated with the idea of performing similar experiments for physiologic study and as a preliminary step for attempting homologous transplantation of lungs.

TECHNIQUE

We followed a technique somewhat different from that reported by Juvenelle and his associates.² Fairly large mongrel dogs were anesthetized with intravenous Nembutal, and respiration was maintained by use of a Pncophore respirator* attached to an endotracheal tube with an inflated rubber cuff. The lung was mobilized and removed. The left main pulmonary artery was mobilized and divided between vascular clamps. The bronchus was then dissected free and divided after clamping the proximal portion with a Potts bronchus clamp. After this, the pulmonary veins and the portion of the left auricle containing the entrance of the left pulmonary veins were dissected by developing the tissue plane posteriorly and opening the pericardium anteriorly. Instead of transecting the pulmonary veins, which necessitates two or more small vessel anastomoses, we performed a resection of a portion of the left auricle by use of the Potts curved, right angle vascular clamp (Fig. 1). With this method we then had to perform only one venous anastomosis; also, the auricle is thick and fairly tough and anastomosis is much easier.

After the lung was removed, we washed the vascular system with saline solution, containing heparin, to remove blood and prevent clotting during the subsequent surgical procedure. In the case of homologous transplantation, the donor dog was heparinized prior to surgery and this washing was not necessary (Fig. 2). The lung was then connected by suture anastomosis. The auricle was anastomosed with a running everted mattress suture of 00000 silk; these were interrupted about three times on the anterior and posterior row. The pulmonary artery was next anastomosed, and circulation was allowed to resume through the lung. The bronchus was next anastomosed; our best results have followed

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*Obtained from the Mine Safety Appliance Co., Pittsburgh, Pa.



Fig 1—This shows the thorax of the recipient animal following left pneumonectomy. Note the clamps used to manage the left pulmonary artery, left main bronchus, and left auricle



Fig 2—The donor lung, ready for anastomosis



FIG 3—This shows the transplanted lung after anastomosis and expansion before closure of the chest.



FIG 4—Roentgen examination one year following autogenous reimplantation of the left lung; A, normal exposure, B, underexposure to demonstrate lung markings

the use of a running, end-to-end anastomosis, using 0000 silk vascular suture material. The lung was then inflated (Fig. 3) and the chest closed. The animals received preoperative and postoperative antibiotics. No heparin was used, other than as mentioned above.

Following surgery, the animals were evaluated by physical examination of the chest, weekly bronchoscopy for the study of the bronchial anastomosis, and frequent roentgen examinations of the chest.

RESULTS

I. Autogenous Reimplantation.—We have one dog with a successful autogenous reimplantation of the left lung. The dog is now living and well, more than one year following surgery, and the reimplanted lung is apparently normal by all studies. Bronchoscopy, one year after surgery, reveals a well-healed area of bronchial anastomosis with no evidence of stenosis by scar contracture. Periodic bronchoscopy revealed the sutures being removed, until now they are all gone and the area is completely healed. Ventilation as observed through the bronchoscope and by auscultation of the chest is normal. Roentgen examination of the chest (Fig. 4) reveals the left lung expanded and aerated, although there is some retraction of the mediastinum to the operative side.

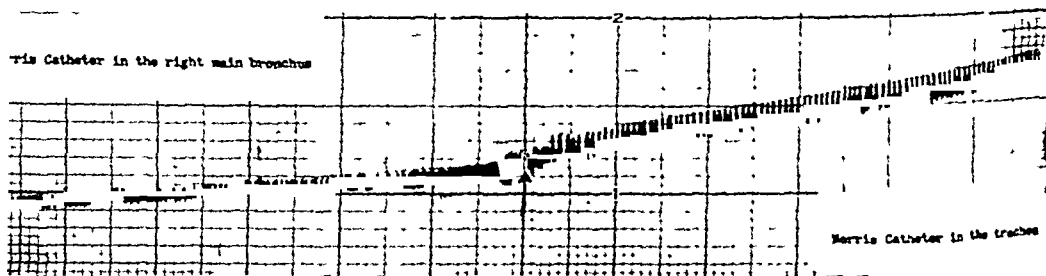


Fig 5—Bronchspirometry tracings with the Norris catheter in the right main bronchus, and the trachea, the difference represents ventilation and oxygen utilization by the left reimplanted lung six weeks following surgery.

Differential oxygen utilization by bronchspirometry, performed six weeks after surgery, revealed a tidal exchange of 108 c.c. with 58 c.c. on the right and 166 c.c. on the left. The bronchspirometry was performed by use of a Norris catheter placed in the right main bronchus and then in the trachea, the position being checked by fluoroscopy. We realize that these figures may not be entirely accurate, due to the possibility of the upper lobe bronchus on the right being occluded, but observation of the tracing leaves no doubt as to ventilation and oxygen utilization being carried out on the left (reimplantation) side (Fig. 5).

II. Homologous Transplantation.—We have performed twenty-five homologous lung transplantations. Although none of the experiments were successful, several were interesting and difficult to explain, due to the results. Table I summarizes the group of experiments. The average length of survival for the entire group was nine days. However, ACTH, 20 mg per day, was used in

TABLE I. HOMOLOGOUS LUNG TRANSPLANTATION

NO.	SURVIVAL IN DAYS	CAUSE OF DEATH	MAJOR FINDINGS
1	0	Hemorrhage	
2	1	Tension pneumothorax	Small leak in bronchial anastomosis
3	1	Hemorrhage	Lung solid
4	5		Lung solid
5	3		Lung solid
6	2		Lung solid
7	4		Lung solid; venous thrombosis
8	17		Lung solid
9	2		Slough of bronchus
10	3	Tension pneumothorax	Lung solid
11	3		Lung solid; slough of bronchus
12	4		Lung solid; thrombosis of auricle
13	9		Slough of bronchus
14	5	Spontaneous pneumothorax	Pulmonary edema of transplanted lung
15	1	Pulmonary edema	Lung solid
16	7		Slough of bronchus
17	4	Tension pneumothorax	Bilateral areas of pneumonia, otherwise normal
18*	27	Distemper	Lung solid
19	10		Lung solid
20	17		Lung solid
21†	4		Lung solid
22*‡	42	Pneumonectomy of transplanted lung (dog living)	Atelectasis; bronchostenosis
23†	10		Lung solid
24†	28		Lung solid
25†	19		Lung solid

*These experiments are described in the text.

†Desensitization with antigen prepared from the donor dog's contralateral lung was used in experiments 21 and 23.

‡ACTH, 20 mg. per day, was used in experiments 22, 23, 24, and 25.

four of the experiments, and in these the survival period was twenty-five days, in contrast to a survival period of only six days in the experiments without ACTH.

All of the animals were in excellent health, and had received penicillin for forty-eight hours before surgery. Animals comparable in size were used. In some of the experiments, litter mates were used, but no difference in survival time was noted. All animals received streptomycin for five full days following surgery; penicillin was given daily until the animals expired.

With the exception of the two experiments to be described, the clinical course followed a consistent pattern. The animals appeared in excellent condition. The day following surgery, they would drink liquids, eat, and were quite willing to walk on a leash. There was ventilation, as evidenced by auscultation and roentgen examination of the lungs. Bronchoscopy, early, revealed a patent bronchus and ventilation. The animals appeared healthy, and the lung apparently was functioning for about half of the survival period. Then the animals became listless, refused to eat, and finally died. With the evidence of clinical deterioration, there was also evidence of lack of aeration by auscultation and roentgen examination (Fig. 6). Bronchoscopy at this time usually revealed

extrinsic compression of the bronchus beyond the suture line, and the bronchus was usually filled with bloody, necrotic debris. Occasionally, a slough of the bronchial anastomotic area was observed.

Examination of the thoracic viscera, following death of the animals, revealed rather consistent findings. The transplanted lung was grossly enlarged in size and weight; it was very dark red and appeared solid on palpation (Fig. 7). On cutting, it appeared as a mass of necrotic tissue. There was no gross pattern consistent with pulmonary tissue. Although the lungs appeared necrotic, some of the specimens which survived longer, and especially those in which ACTH was used, appeared more solid and firm in contrast to the extremely friable specimens of short-term survival.



Fig. 6.—Roentgen examination following homologous left lung transplant to demonstrate characteristic finding after the animal develops lack of aeration.

There was gross evidence of bronchial slough in four specimens; the slough did not appear to involve the entire thickness of the bronchial wall, but was usually confined to the mucosa. However, of these four with evidence of bronchial slough, three expired due to tension pneumothorax. Most of the specimens revealed thrombosis of the smaller, peripheral pulmonary veins, but



Fig 7—Photograph of thoracic viscera showing characteristic findings in the homologous transplanted left lung. The lung is large, dark red, and solid.

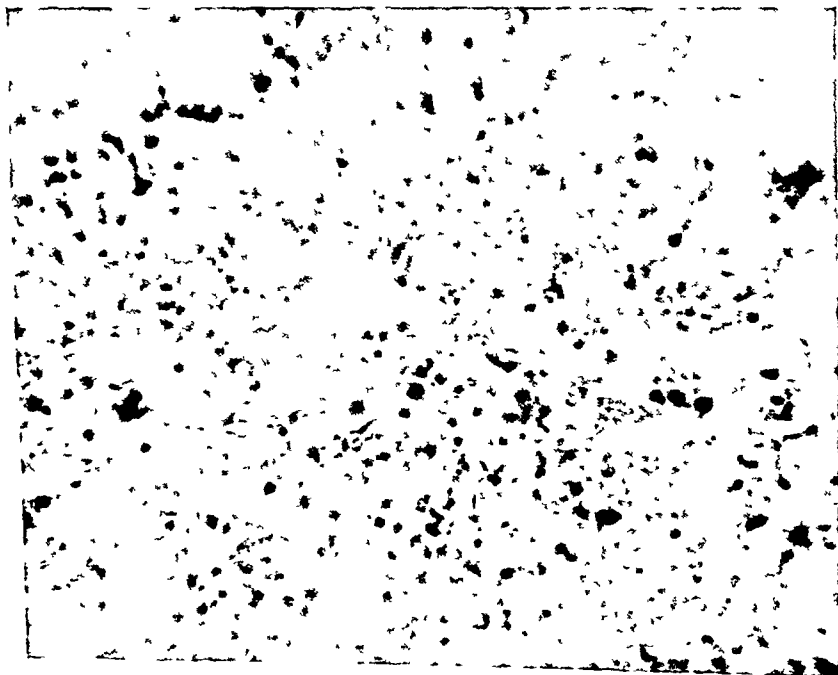


Fig 8—Photomicrograph of a section from a homologous lung transplant, showing characteristic findings. (See text)

thrombosis of the auricular anastomotic suture line was present in only two specimens. No thrombosis of the pulmonary artery occurred. The bronchus was usually almost completely compressed due to extrinsic compression by the enlarged solid lung, and the bronchial lumen throughout the lung was filled with necrotic debris. The animal's own lung was usually normal, although occasionally small areas of bronchopneumonia were observed. None of the animals developed an empyema or wound infection.

Microscopic examination (Fig. 8) of the transplanted lung usually revealed consolidation due to filling of the alveoli with erythrocytes and polymorphonuclear leukocytes. Most of the lung tissue had undergone necrosis. In the larger veins of the lungs, recently formed thrombi were seen made up of fibrin, platelets, erythrocytes, and a few leukocytes. Throughout the lung there was a diffuse polymorphonuclear leukocytic infiltration, most marked about the smaller and medium-sized blood vessels. Examination of sections through the bronchus at the point of anastomosis revealed no cellular reaction at the site of the suture material.

Desensitization.—In two experiments, we tried desensitization of the recipient animal by use of an antigen prepared from the donor animal's contralateral lung.* A right lobectomy was performed on the donor animal, and a sterile preparation of lung tissue antigen was prepared. Although the strength of the antigen was unknown, it was given to the recipient in increasing doses, subcutaneously, starting with 0.2 c.c. and increasing to 0.5 c.c. on the seventeenth, fifteenth, twelfth, eighth, fifth, and last days before transplantation. On the basis of sensitization studies in rabbits, this should produce sensitivity and antibody formation. After transplantation, in an attempt to block new-formed antibodies, the antigen was continued; 0.5 c.c. was administered every three days, until the animal expired. This was only used in two experiments. The survival in one, without supplemental ACTH, was four days; in the other, with ACTH, the survival was ten days. Although statistically of no significance, the antigen, as used, appeared to be of no value. The pathology of the specimens did not reveal any differences from the ones in which antigen was not used.

ACTH.—In an attempt to diminish or, perhaps, prevent the development of sensitivity in the recipient animal, we administered ACTH to four animals following transplantation. We used 20 mg. per day in two divided doses; this was continued as long as the animals survived. It is of interest to note that the average survival time in these four experiments was twenty-five days, in contrast to only six days in those experiments in which ACTH was not used. In addition, the animals receiving ACTH had an improved clinical course following surgery, as evidenced by an increase in appetite; they engaged in more activity, and the length of time the transplanted lung apparently functioned was more than half the period of survival, as usually found in other animals. Moreover, once the transplanted lung developed lack of aeration, the animals continued to be active and appeared well until one or two days before

*The antigen was prepared by Dr. W. L. Gaby, of the Department of Bacteriology.

death. Although the survival period was increased, the pathology of the specimens did not appear different from those animals not receiving ACTH.

EXPERIMENT 18.—This experiment was interesting and difficult to explain due to the results. Homologous left lung transplantation was performed and the animal received the usual antibiotics postoperatively. No ACTH was used. Following surgery, the animal appeared to be in excellent health and the lung appeared to function. On the seventh day after surgery, bronchoscopy revealed the site of anastomosis to be healed except for a few small areas of granulation tissue. The animal continued in good health, and bronchoscopy seventeen days after surgery revealed only a minimum of contracture at the site of anastomosis.

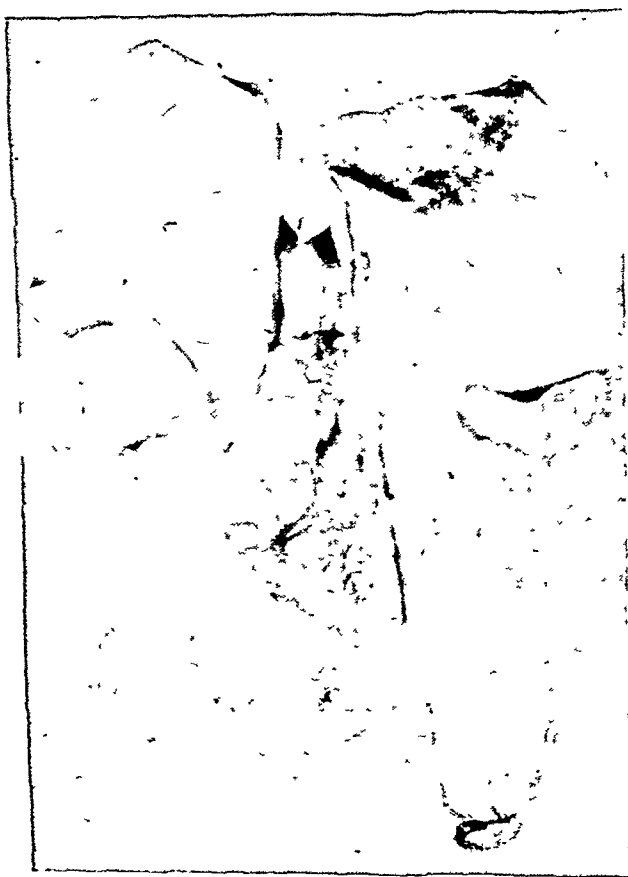


FIG. 2.—Photograph of the thoracic viscera, twenty-seven days following left homologous lung transplantation. This animal died due to distemper; note the bronchopneumonia (complication of distemper?) and similar appearance of both lungs. (Experiment 18.)

Twenty-three days following surgery, the animal developed signs and symptoms of distemper (all of the animals are vaccinated for distemper on admission), and consultation with a veterinarian was obtained. The animal was treated with anticanine distemper serum and received parenteral fluids (all antibiotics had been maintained since surgery). In spite of therapy, the animal developed evidence of complicating meningitis and expired twenty seven days after surgery.



Fig. 10.—Roentgen examination of thoracic viscera, shown in Fig. 9.

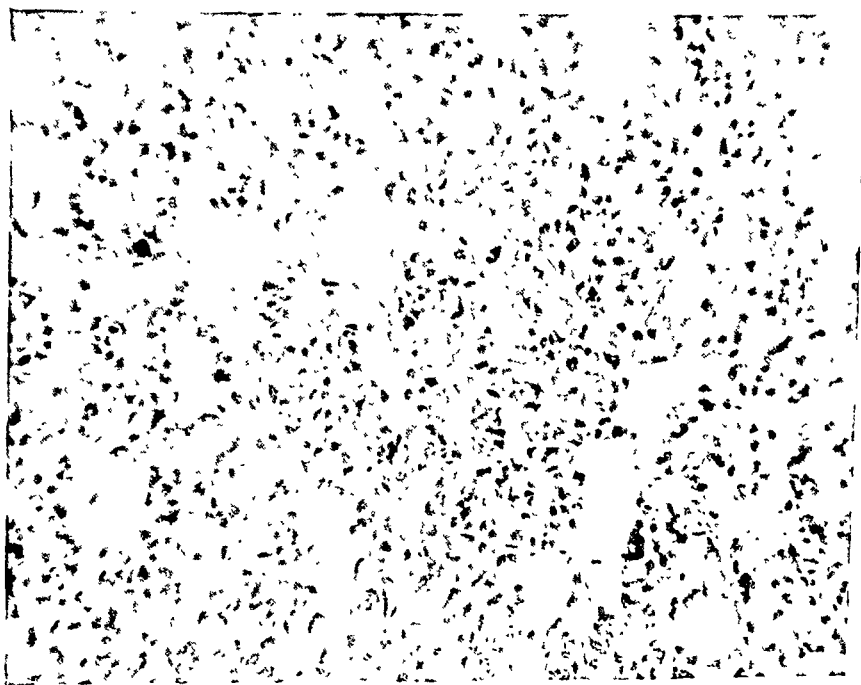


Fig. 11.—Photomicrograph of the transplanted lung. (See Figs. 9 and 10.)

Examination of the thoracic viscera revealed the presence of bilateral, small areas of bronchopneumonia (this could easily be a complication of the distemper), but the transplanted lung was aerated, soft, crepitant, and appeared normal (Fig. 9). Roentgen examination of the specimen revealed aeration of the transplanted lung (Fig. 10). There was no evidence of thrombosis in any of the pulmonary vessels. The bronchial anastomosis revealed evidence of some slough of the mucosa of the transplanted lung, near the suture line, but this had healed with only a minimum of scar contracture. Microscopic examination (Fig. 11) revealed an acute lobular pneumonia characterized by polymorphonuclear leukocytes within the lumina of the small bronchi, infiltrating their walls, and extending into adjacent alveoli.

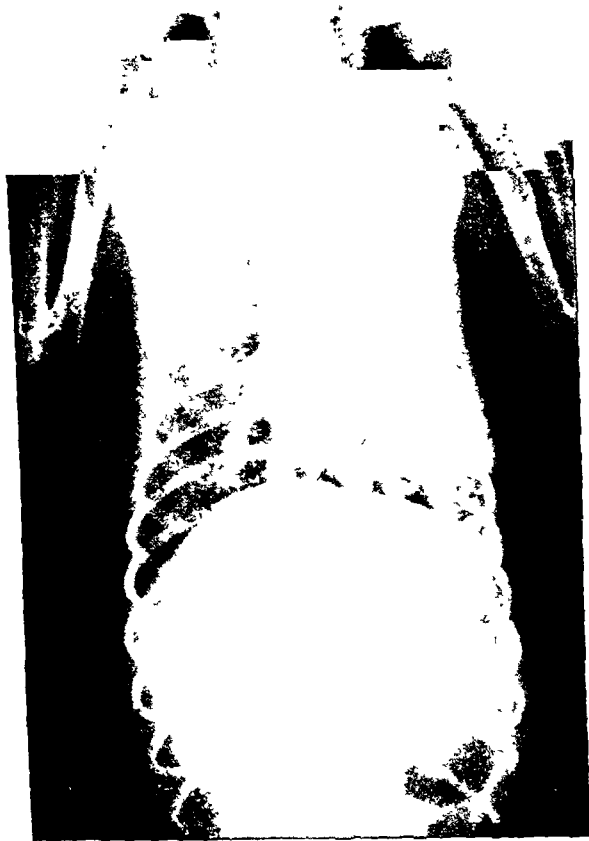


Fig. 12—Roentgen examination three weeks following left homologous lung transplantation. (Experiment 22.)

There were focal areas in which the lung was atelectatic, and it may be noted that the tissue was well preserved and there was no evidence of necrosis. The blood vessels were not remarkable, with the exception of a few recently formed thrombi which were seen in small veins. The mesothelial cells of the pleura were prominent; however, this tissue was not otherwise remarkable. Most of the capillaries and smaller vessels of the lung were engorged with erythrocytes, and in some areas there was pink edema fluid in the alveoli.

We are unable to explain the apparent success in this experiment, although the animal died, due to the complications, apparently, of distemper. The lung, by gross and microscopic examination, appeared to be living and functioning until death. The only explanation we can offer is that the state of "tissue sensitivity" had not yet had time to develop and produce the characteristic changes.

EXPERIMENT 22.—In this experiment, the animal received ACTH in addition to the usual postoperative care. The animal was unusually active, and appeared healthy, and roentgen examination of the chest revealed an aerated left lung (Fig. 12). Repeated bronchoscopy revealed good healing and no contracture at the site of anastomosis. However four weeks following surgery, the animal developed a few thrombi throughout the transplanted lung, and bronchoscopy revealed clear secretions and rather friable granulation tissue at the site of bronchial anastomosis. Breath sounds after bronchoscopy were excellent. Although the lung appeared aerated by roentgen examination for four weeks, on the thirty-first day after surgery, the lung was atelectatic. Bronchoscopy at this time revealed almost complete stenosis

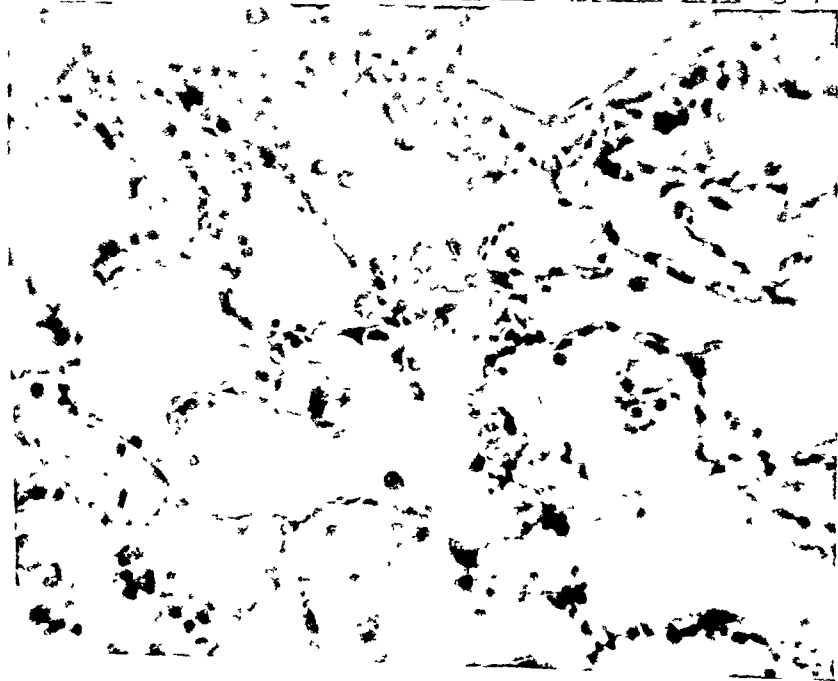


Fig. 13.—Surgical specimen pneumonectomy forty-two days following homologous lung transplantation. Grossly, the lung was atelectatic, but otherwise normal. (Experiment 22.)

of the bronchus by granulation tissue at the site of bronchial anastomosis. Several attempts were made at bronchial dilatation without success, and on the forty second day following transplantation, an exploratory thoracotomy was performed. It was our hope to resect the area of obstruction and repair it with a dermal graft, after the method of Gebauer.³ On exploration, the lung had the appearance of atelectasis, but was otherwise normal. The bronchus, on mobilization, appeared stenosed from the site of previous anastomosis near the carina, and the stenosis extended beyond the hilum into the branch bronchi. Due to the findings, the transplanted lung was removed. The animal made an uneventful recovery.

The surgical specimen was atelectatic, but otherwise normal (Fig. 13). No thrombosis of the vessels was found. The main bronchus and the beginning of the branch bronchi had apparently developed a slough of the mucosa and part of the submucosa, and the resulting granulation and contracture produced complete stenosis. Distal to the stenosis, the bronchi

A.



B.

Fig 14—A and B, Photomicrographs of the transplanted lung. (See Figs. 12 and 13.)

were filled with clear, mucoid exudate, but were otherwise normal. Microscopic examination of sections through the main bronchus revealed severe distortion due to scarring and foci of granulation tissue with necrosis, capillary ingrowth, fibroblastic proliferation, and infiltration by lymphocytes and a few eosinophils. Occasional bits of suture material were present within the granulomatous foci. The walls of the small and medium-sized arteries revealed muscular thickening. Other large bronchi were diffusely infiltrated by polymorphonuclear leukocytes and contained similar exudate within their lumina. There was an acute lobular pneumonia present, and in some areas focal collections of lymphocytes were seen, particularly near the walls of small bronchi. In many sections of the lung there was atelectasis and occasional alveoli contained pink edema fluid. In many areas collections of polymorphonuclear neutrophils appeared to be localized just beneath the pleura. The blood vessels were not remarkable. Many sections of lung were uninvolved by inflammatory or mechanical change (Fig. 14).

COMMENTS

The successful autogenous reimplantation of the left lung, now followed for one year, demonstrates that technically the transplantation of lungs is feasible. However, homologous transplantation has not been successful, due to, perhaps, for want of a better term, the production of tissue sensitivity in the recipient with resultant death of the donor tissue. The course of events following the transplantation of the lungs was similar to that in homologous skin grafts. In the only other report we could find, concerning transplantation of lungs from one dog to another, Staudacher, Bellinazza, and Pulin¹ had an average survival period of six to eight days. In their experiments nonsuture anastomosis was used since preliminary experiments with suture technique had all failed due to thrombosis. Our average survival period was nine days; however, it was six days among the animals that did not receive ACTH and the average survival period was extended to twenty-five days among those animals receiving ACTH. Also, all of our experiments were performed using suture anastomotic technique, and without anticoagulants postoperatively. Of the twenty-five homologous transplantations, thrombosis of the suture line in the auricular anastomosis occurred in only two; there was no instance of thrombosis in the pulmonary artery anastomoses. In two experiments we obtained satisfactory results as far as the life of the donor lung was concerned. In one, the animal died twenty-seven days after surgery due to distemper, and the lung appeared normal; in the second, atelectasis developed due to bronchostenosis following slough of the bronchus with formation of granulation tissue and scar contracture. Pneumonectomy forty-two days after transplantation revealed only atelectasis of the transplanted lung.

The problem of bronchial slough is undoubtedly related to lack of an adequate blood supply, due to loss of the bronchial artery following dissection and transection of the common bronchus. Ellis, Grindlay, and Edwards⁵ state that slough will always follow loss of the bronchial arterial supply. However, although this is an important problem should transplantation become clinically feasible, it is not insurmountable. Many of our animals did not develop slough as evidenced by periodic bronchoscopy and examination of the post-mortem specimens. Also, there has been no difficulty observed in our animal having an autogenous reimplantation during the one year following surgery.

The problem at the present time would seem to be that of homologous transfer of any tissue. The problem is being studied by many investigators, and, although unsolved, it should be conquered by the combined efforts of immunologists and tissue culture workers.

SUMMARY

1. We have presented our technique for experimental transplantation of lungs in dogs.

2. A successful autogenous reimplantation followed for one year is reported. All studies on this animal are normal.

3. Twenty-five homologous, left lung transplants were performed with an average survival time of nine days. The average survival time without the use of ACTH was six days; with ACTH it was twenty-five days.

4. Desensitization by the use of antigen prepared from the donor animal's contralateral lung was used in two experiments, without any evidence of benefit.

5. Details of the clinical course and pathology of the usual case are described.

6. Details of two cases with apparent success are presented. In one, the animal died after twenty-seven days due to distemper, but the transplanted lung was apparently normal. In the other, atelectasis developed after four weeks due to bronchostenosis; pneumonectomy on the forty-second day after transplantation revealed atelectasis and bronchostenosis, and an otherwise normal lung. The only explanation we can offer for the apparent success in these two experiments is that the so-called state of tissue sensitivity had not yet had time to develop.

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RESECTION OF AN ACQUIRED COARCTATION OF THE LOW THORACIC AORTA AND REPLACEMENT WITH A PRESERVED VESSEL GRAFT

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NEW YORK, N. Y.

THE coarctation commonly treated by surgery occurs as a congenital anomaly immediately below the origin of the left subclavian artery. However, in the case being reported, a coarctation which was thought to be acquired was located 6 cm. above the diaphragm. An obliterated left subclavian artery was also found. The stenotic aortic segment was successfully treated by resection and implantation of a preserved human homograft. The first report of a coarctation located near the diaphragm was made in 1835 by Schlesinger,¹ and less than a dozen cases have been described since that time.

CASE REPORT

R. R., 905357, a 23-year-old Puerto Rican single woman, was seen in the outpatient clinic at Presbyterian Hospital in September, 1948. She complained of nausea and epigastric discomfort of two years' duration. During the previous year she noticed occasional pains radiating around the left costal margin, which seemed to be worse after eating. In the few months before examination, she experienced palpitation, headaches, and dyspnea when walking up two flights of stairs.

The physical examination revealed a small, slender, young woman in no distress. She had normal fundi, no unusual pulsations in the neck vessels, and the thyroid gland was of normal size. The lungs were clear and the heart was not enlarged. A systolic murmur was heard only at the apex. The pulse rate was regular at 80 beats per minute. The blood pressure was 140/80 mm. of mercury in both arms. The abdomen was negative. Femoral and dorsalis pedis pulses were palpable but weak, and her feet were cold. Laboratory reports of hemoglobin, sedimentation rate, urinalysis, serology, chest film and fluoroscopy, cholecystogram, and gastrointestinal series were normal. *Escherichia coli* cysts were found in the stool. The symptoms abated with low dosage of phenobarbital and reassurance.

She returned in December, 1949, feeling weak. Again, except for a mild anemia and *Escherichia coli* cysts in the stool, the complete examination was not remarkable. The patient presented no complaints on a return visit in January, 1950.

On Oct. 26, 1951, she was referred by the Union Health Center with the diagnosis of coarctation of the aorta. At this time there was a blood pressure of 190/100 mm. of mercury in the right arm, and 130/95 in the left arm, and a marked difference in radial pulses was noted. The dorsalis pedis pulses were absent. These findings were further confirmed during a complete work-up in November, 1951. A systolic murmur was heard over the precordium, maximal over the aortic and mitral areas. Again a normal serology, sedimentation rate, and urinalysis were recorded. Slight anemia persisted. The chest film was still negative (Fig. 1).

On Nov. 12, 1951 she was admitted to the medical service. Repeated determinations of blood pressure in the arms revealed readings of 200/85 on the right and 120/90 on the left

From the Department of Surgery, College of Physicians and Surgeons, Columbia University, and the Surgical Service of Presbyterian Hospital.

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Fig. 1.—The preoperative chest film reveals a normal aortic knob and cardiac contour. There is no notching of the ribs.

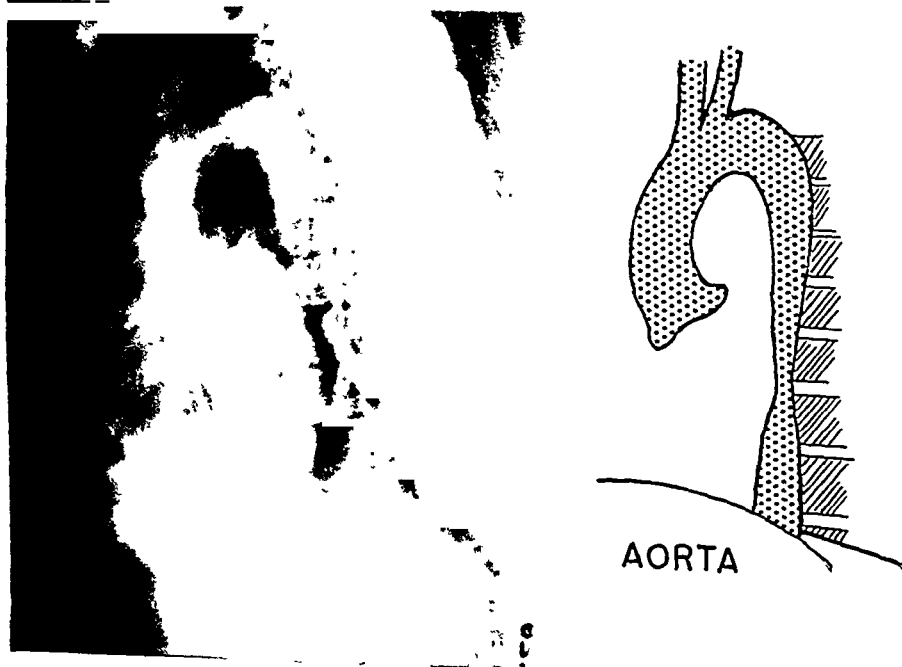


Fig. 2.—Angiocardiogram shows the long narrowed segment of low thoracic aorta. The maximal stenosis lies opposite the anterior junction of the ninth and tenth thoracic vertebral bodies. The left subclavian artery does not opacify.

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A linear fracture of the aorta was noted where the proximal clamp had been placed but no leakage occurred. Slight transient bleeding was observed at the anastomoses. Additional simple sutures were used in two places for hemostasis. A drainage tube was placed laterally through the ninth intercostal space, and 100,000 units of penicillin was instilled into the pleural space. A total of 1,200 c.c. of whole blood was given during operation.

PT. R-R

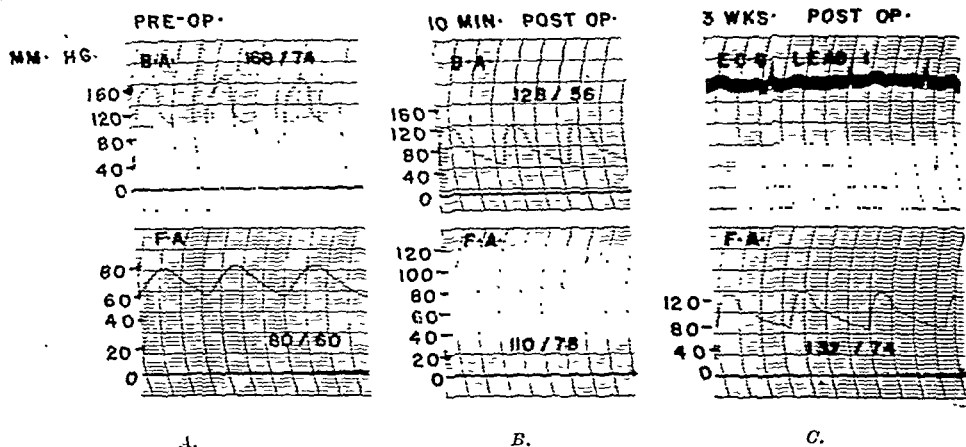


Fig. 4.—Intra-arterial pressure tracings from the brachial and femoral arteries. A. Before operation. B. Immediately after restoring aortic blood flow through the graft. C. Electrocardiogram and femoral arterial pressure obtained three weeks after operation. Note the dirotic notch.

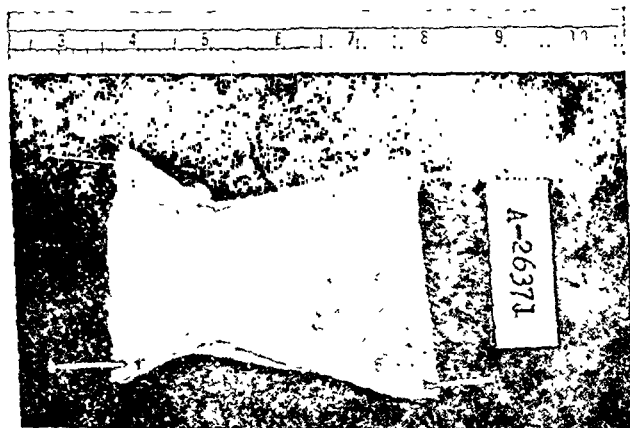


Fig. 5.—Gross specimen reveals a valvelike stricture close to the left edge. Note the marked calcification in the proximal aorta, shown at right.

The excised segment revealed a gradual narrowing to a midpoint at which there was a localized stenosis, almost resembling a valve. The adventitia was thickened, as was the intima. There was moderately severe calcific degeneration of the media in the few centimeters proximal to the point of maximal narrowing. This was not observed distally except for a 2 mm. plaque (Fig. 5). The microscopic picture revealed marked thickening of the intima. The media had areas suggesting edema; in addition, there was spotty cal-

side. Electrocardiogram showed only left axis deviation. A Nickerson ballistocardiogram on Nov. 16, 1951, demonstrated small K waves, very suggestive of coarctation. The chest film was normal in all respects and laminograms added no further information. She was transferred to the Surgical Service on Nov. 16, 1951. Blood volume, hematocrit, and blood urea nitrogen were in the normal range. On Nov. 19, 1951, angiocardiography was performed. An elongated narrowing of the aorta, 9 cm. in length, was seen opposite T 9 and T 10 (Fig. 2). The left subclavian artery was not visualized. The patient noted anginal discomfort during the next five days.

On Nov. 30, 1951, thoracotomy through the seventh rib bed was performed, under intratracheal ether anesthesia. The long narrowed segment of thoracic aorta was found just above the diaphragm, as visualized (Fig. 3, *A*). The pleura overlying this segment was thickened and very adherent to the adventitia of the aorta. No other evidence of pleuritis or of pulmonary inflammation was observed. The entire intrathoracic portion of the left subclavian artery was obliterated, and appeared to be a fibrous cord, 0.5 cm. in diameter. The upper thoracic aorta, left common carotid, and internal mammary arteries were normal. The intercostal arteries were normal except two pairs distal to the point of maximal narrowing. These were dilated to twice normal size. Systolic thrill was easily discerned in the few centimeters distal to the narrowest point. A segment of low thoracic aorta, including the 9 cm. narrowed zone, was mobilized by reflecting the pleura and dividing five sets of intercostal arteries.

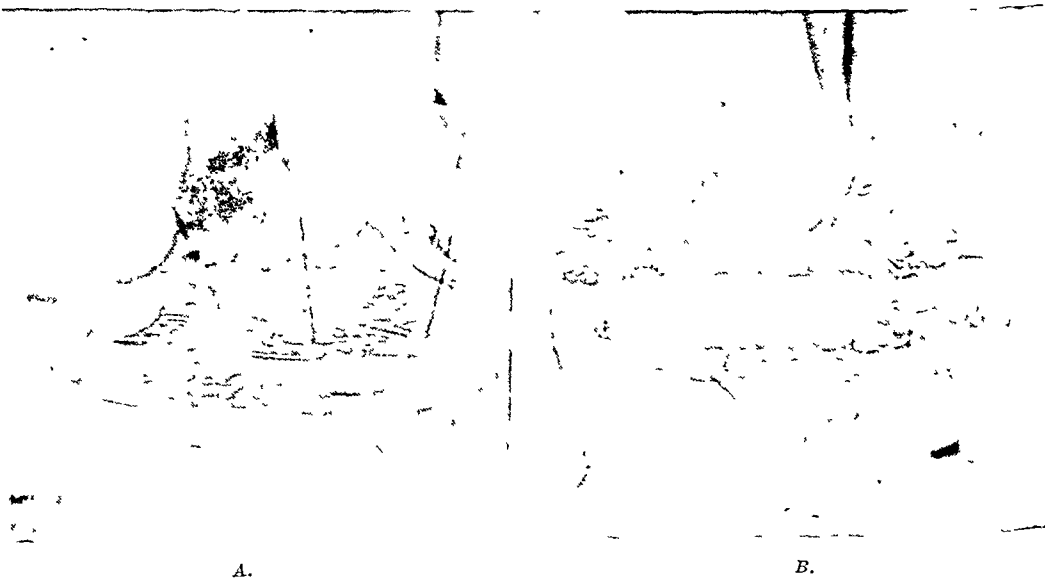


Fig. 3.—*A*, Operative exposure of the narrowed segment. The site of maximal constriction can be seen at the extreme right. *B*, Preserved human homograft replacing the long narrowed aortic segment.

Straight Potts coarctation clamps were applied 1.5 cm. above and below the narrowed segment. This portion was then resected in its entirety and a perfectly matching homograft, 8 cm. in length, was implanted (Fig. 3, *B*). Marked irregular, intimal thickening of the adjacent aorta was seen at the cut ends. A continuous over-and-over suture of 00000 Deknatel silk was used between equidistant traction sutures, for each anastomosis. The clamps were removed after thirty-six minutes of occlusion. Blood flow through the graft was excellent despite slight but unavoidable constriction at the proximal suture line. Continuous recordings of intra-arterial brachial and femoral pressures were made during operation,² and revealed a marked improvement in cardiovascular dynamics when aortic blood flow was restored (Fig. 4).

cification and a patchy disruption of the elastic fibers. There was moderate thickening of the adventitia from thick hyaline collagen fibers. Throughout the wall, there were perivascular accumulations of round cells (Fig. 6, a, b, and c).

Because of the aortic degeneration and the long length of the graft, 35 mg. of heparin was administered subcutaneously every three hours, beginning six hours after the operation. The condition of the patient was excellent until the morning of the fourth day, Dec. 4, 1951. At 7:30 A.M., she noted pain in the left chest posteriorly and felt faint. The blood pressure fell to 110/50 mm. mercury and the pulse rate rose to 140 per minute. A moderately rapid administration of 500 c.c. of blood intravenously restored blood pressure to 130/80 and the pulse rate to 110 per minute. Anticoagulation was stopped immediately and a chest film revealed moderate left hemothorax. During the next day, the hemothorax increased but vital signs were good. Aspiration was unsuccessful. Regression of the hemothorax was observed during the next two weeks, and the patient was allowed to walk on Dec. 20, 1951. Electrocardiogram was normal and the ballistocardiogram showed improvement, with increased K waves.

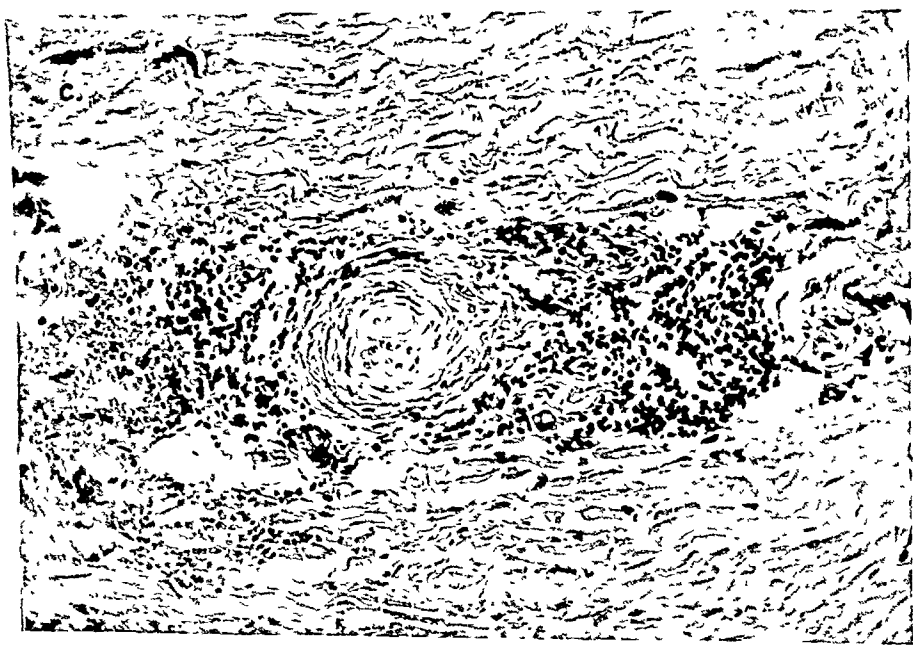


Fig. 6.—c, Perivascular round-cell infiltration in the outer adventitial layer. $\times 400$, hematoxylin and eosin stain

Because of recurrence of epigastric pain and nausea, study of the digestive tract was again undertaken. The gastrointestinal series was negative, but the gall bladder failed to show function. The patient's symptoms were improved on a low fat diet and Banthine. Because of the marked resolution of the hemothorax, decortication was not planned. The patient was discharged Jan. 7, 1952, with a blood pressure of 120/80 in the right arm and palpable dorsalis pedis pulses.

On Jan. 19, 1952, she noted sudden precordial pain and was admitted again briefly for study. The electrocardiogram was normal, and the chest film showed further resolution of the hemothorax. The sedimentation rate was slightly elevated, but blood culture and white count were normal. The medical consultant considered the attack to be angina, and she was advised to take nitroglycerin tablets if necessary. At subsequent visits in February, March, May, and November, 1952, she had a normal brachial blood pressure and pal-

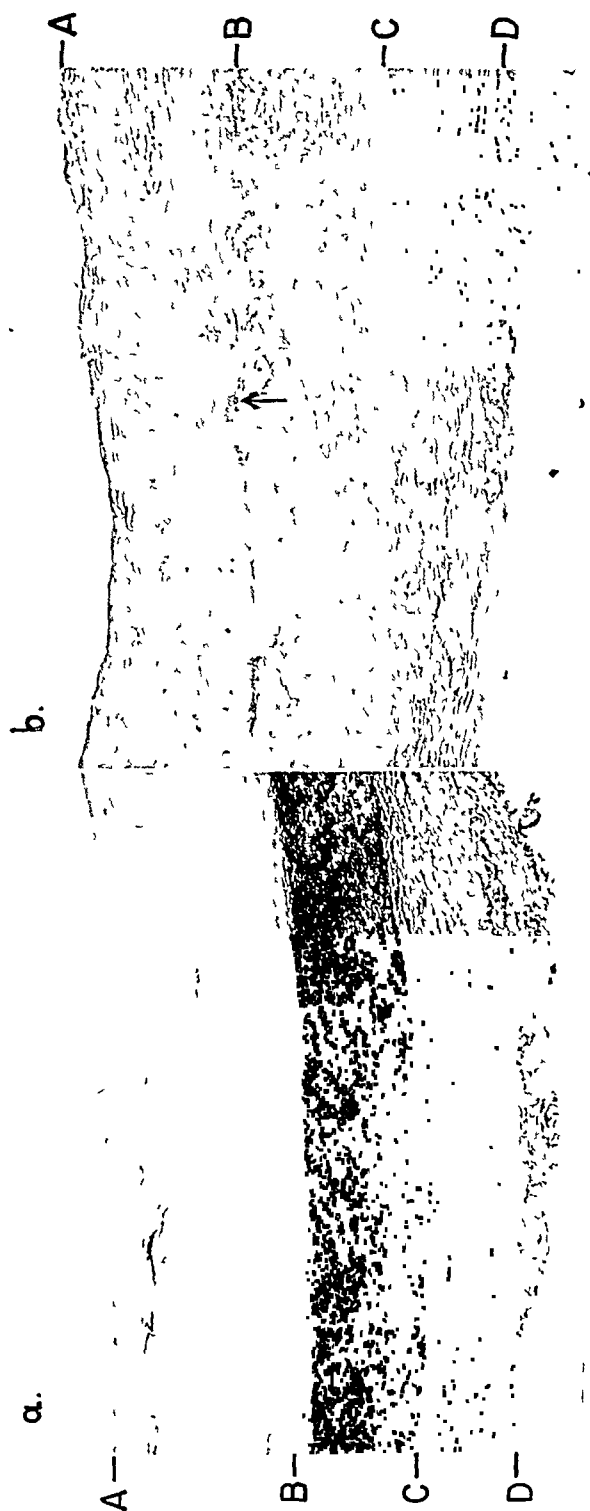


Fig 6.—Photomicrographs of the aortic wall in the narrowest segment media (BC) reveals a patchy destruction of the elastic framework $\times 20$, Verhoeff elastic stain b. The intima (AB) and adventitia (CD) are thickened. The ventrilia (OD) are acellular zones. There are scattered round-cell collections, especially about the small arteries (see arrow). $\times 20$, hematoxylin and eosin stain.

located just above the diaphragm and restored continuity with a preserved aortic homograft. There was also a large aneurysm located proximal to the stenosis. Glenn and his associates⁷ had a patient with a long stenosis involving the low thoracic and upper abdominal aorta. Because of its length and location, an ingenious auxiliary by-pass was effected by means of the splenic artery.

Other reports of similar cases include those of Schlesinger,¹ Hasler,⁵ Schleeckat,⁹ and Freeman and his co-workers.¹⁰ The latter visualized the lesion in a 14-year-old girl, but because of its length and location, they remarked that she had been spared an unnecessary exploration. Since a graft was not available, surgical correction would have been impossible. The value of preoperative visualization in planning surgery of such a lesion was further borne out in the unfortunate case of Olim.³ We do not advocate angiography in all typical cases of coarctation, but if there are any atypical findings, visualization should be performed. A suitable aortic graft⁶ is always available during all of our operations for coarctation. Such a precaution will prepare the surgeon for most eventualities, although in the case of Glenn and his associates⁷ the lengthy stenosis in the region of the coeliac axis did not permit the use of a graft.

The graft employed in our patient was removed twelve days previously under sterile conditions from a 30-year-old man who died from trauma. It was one of several used with satisfactory results after having been obtained a considerable time beyond the usual six-hour limit and preserved at 4° C. in Hank's solution and 10 per cent serum. A discussion of the use of these grafts and proposed modifications of criteria governing acceptability of vessel grafts will be reported separately.^{12, 13}

The use of anticoagulant drugs with aortic grafts has been studied experimentally.^{14, 15} A decrease in the number of occlusions by thrombosis in certain aortic grafts implanted into the abdominal aorta of dogs was noted. We previously used heparin after implanting a graft in the thoracic aorta of a 17-year-old boy with coarctation, but have not done so in three other similar cases. In the patient being reported, heparin was used because of the location and length of the graft, and because of the calcific degeneration of the adjacent aorta. Also, a greater than usual amount of silk suture was present in the aortic lumen with the simple continuous anastomosis. The drug was begun six hours postoperatively, by which time the sealing thrombus should have formed at the suture lines. The hemothorax which occurred on the fourth day after operation presumably was not caused by heparin, since the bleeding was short lived, localized, and attended by chest pain. The type of pain suggested dissection through innervated aorta, and the fracture line previously noted at the site of the proximal clamp seemed the most likely site for the bleeding. Hemorrhage of almost fatal degree occurred from this same cause in another adult patient with aortic degeneration proximal to a coarctation. In that patient, a 5 mm. crack in the aortic arch was repaired during massive intra-aortic transfusion. So in this case, since the suture lines

*From the New York Vessel Bank, supported by a grant from the New York Heart Association.

pable pulses in the distal extremities. A roentgenogram of the chest in March, 1952, revealed complete resolution of the hemothorax (Fig. 7). She remained without symptoms and had married by the time of her next visit in February, 1953, fifteen months following the operation.



Fig. 7.—Chest film obtained about three months after left hemothorax occurred. Note the complete spontaneous resolution of this process.

DISCUSSION

While surgical repair of coarctation occurring in the usual site is no longer considered rare, only five operated cases with stenosis situated just above the diaphragm have been noted in the literature. Olim³ explored a 20-year-old woman with the clinical diagnosis of coarctation. Because his approach was through the fourth interspace, another operation had to be performed to permit better exposure of the stenosis which was situated 5.0 cm. above the diaphragm. Although an aortic segment only 1.7 cm. was excised, end-to-end repair was impossible. Before an iliac vein graft could be obtained, the patient's condition became critical and operation had to be abandoned. This patient died five hours later. Bahnson and his co-workers⁴ reported the case of a 17-year-old girl who had a long narrow stenosis in the mid-descending thoracic aorta. Because a graft was not available, resection was not feasible. Instead, a low dorsal sympathectomy was carried out with a resultant lowering of the brachial blood pressure. Beattie and his associates⁵ reported a 19-year-old woman in whom the narrowing was 6.5 cm. long and was situated exactly where the lesion was in our patient. The long narrow segment was resected, and a 7 cm., 23-day-old graft was implanted. The results were highly successful. Our surgical approach was identical and the end-result has been very satisfactory. Brock⁶ resected a coarctation

SUMMARY

The case of a 23-year-old girl with a long coarctation of the low thoracic aorta is presented. A 9 cm. segment was excised and replaced by an 8 cm. preserved aortic homograft. An obliterated left subclavian artery was also found. A left hemothorax occurring on the fourth postoperative day was believed to be due to a leak from an aortic fracture caused by the proximal aortic clamp. The end result was quite satisfactory with complete resolution of the hemothorax, and normal brachial blood pressure and blood flow to distal extremities. The character and site of the lesion, as well as the medical history, support the theory that she had an acquired coarctation.

The author acknowledges the assistance of Dr. Joseph Ford, Dr. F. F. McAllister, Dr. G. H. Humphreys, and Dr. Raffaele Lattes in the documentation of this case.

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were secure and the graft was in good condition, we must assume that the leak came from the fracture site. We plan angiography in the future to determine whether or not function of the graft has been altered and if any aneurysm has formed where the proximal clamp had been placed.

Precordial pain or angina pectoris occurring in this patient was of some concern, since fatal myocardial infarction occurred six weeks after use of an aortic graft in a 45-year-old man with coarctation. He had had all the signs of advanced hypertension, with sclerosis of the proximal aorta. The fall in coronary perfusion pressure after removal of the coarctation may have been a major factor in the subsequent coronary occlusion. For this reason, we prescribed nitroglycerin for this young woman. Fortunately, she has had no recurrence of angina since the single attack four weeks after the operation.

The cause of the coarctation is most intriguing. Analysis of other reported cases indicates that young women were affected in all but one.⁹ The lesion was always an elongated narrowing with marked periaortic fibrosis. In one young girl, there had been a cerebral embolus or thrombosis five years before,¹⁰ and in our patient there was an obliteration of the left subclavian artery. At repeated examinations of our patient from September, 1948, through January, 1950, there were noted equal pressures in both arms, pulses in the legs and feet, and absence of hypertension. Despite negative history of infection or significant illness, and repeated normal sedimentation rate and white cell count, there may have been a localized aortitis. It is questionable whether the epigastric discomfort and certain other vague complaints referable to the left lower chest prior to the initial visit can be taken to indicate that the active process had already occurred. At the patient's visit in October, 1951, hypertension in the right arm, diminished pulsation and pressure in the left arm, and an absence of pulses in the legs were noted for the first time. We suggest that the coarctation was an acquired condition, and wonder if all those reported distal to the usual position might not have been acquired also. Hasler⁶ held the same opinion, concluding that this lesion results from a localized inflammation and a stenosing organized thrombus. The rare occurrence of similar lesions of the aorta below the diaphragm, also without a basis related to embryologic development, support this theory.

The specimen in our case revealed a thickening of the wall in the area of narrowing, and there was also a valvelike localized stenosis in the mid-portion. The pleura overlying the adventitia was slightly thickened and very adherent, as is noted following pleural inflammation. The microscopic picture of a thickened intimal zone, areas of degeneration in the elastic framework of the media, and thickening of the adventitia, with hyaline collagenous fibers and accumulations of round cells about the vessels, have been noted occasionally in the congenital type, however.

The concept of an acquired coarctation is presented in the hope that future cases may be investigated from this viewpoint. In the cases reported so far, the previous medical history was insufficient to determine the exact time of onset of signs of coarctation, although a late onset is suggested in the case of Glenn.⁷

behind the origin of the right coronary artery. This suture is tied and taken out into the above-mentioned groove behind the dissected superior vena cava. Then another suture is anchored behind the inferior vena cava in the annulus fibrosis, tied, and carried out in the dissected groove. Then the two sutures can be tied together over a piece of fibrin foam in the dissected groove between the right and left auricle. As the sutures are drawn taut the interauricular defect is occluded without obstruction of pulmonary veins and venae cavae. Autopsy specimens from dogs (Söndergaard) clearly demonstrated the effectiveness of the method in experimental animals. Husfeldt and Söndergaard (1952) successfully applied the method on human beings.

The important feature of this method is the dissection between the left and right auricle beginning between the pulmonary veins and the vena cava. This will exclude an obstruction of pulmonary veins and vena cava. However, in patients with a very large atrial defect which is directly in continuity with the bicuspid and the tricuspid valves a complete closure of a septal opening cannot be obtained.

4. These experimental methods were only used in dogs. Cohn, 1947, described a technique used on dogs in which the right auricular wall was pushed in to plug a septal opening and the inverted wall was sutured to the septum around the defect. The sutured part of the auricular wall was cut off by a wire snare and allowed to remain as a free patch over the defect. The hole in the auricular wall was closed by a running silk suture placed beforehand.

5. During 1948 Martin and Essex experimenting on dogs, introduced a sheet of polythene covered with an inverted segment of vein into the right atrium over the defect. Three silk sutures with straight needles attached to the graft were brought out of the right auricle at points in the plane of the atrial septum.

6. In 1949 Dodrill described a clamp by which the atrial walls could be approximated against the septum. Through the ring in the clamp the right auricular wall could be opened and a small defect sutured.

These experimental methods worked out on dogs are limited by the fact that the atrial septal defects of a size to produce symptoms in man cannot be obtained in the experimental animal. Thus these methods are not applicable to patients, other than those with small defects.

B. Closed Intracardiac Tactile Methods.—

1. Bailey and his co-workers in 1952 introduced an intra-auricular tactile method for closure of the septal defect. A finger is inserted through the auricular appendage to guide the placement of sutures through the right atrial wall and the margin of the defect and again out through the atrial wall. Thus the lateral right auricular wall is attached to the septum at the periphery of the defect, plugging the hole. Six cases are reported, four with a successful outcome. However, a large defect without a septal rim and in continuity with the bicuspid and tricuspid valves cannot be treated by this method for obstruction of the vena cava or tricuspid valves may result.

THE SURGICAL CLOSURE OF INTERAURICULAR SEPTAL DEFECTS

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THE many different surgical procedures that have been described for the correction of interatrial septal defects indicates that so far none is entirely satisfactory.

In this communication the principles for closure of interauricular septal defects will be discussed and a new method presented.

EARLIER TECHNIQUES

1. *Blind Methods.*—

1. In 1948 Murray published an article describing a method of passing sutures through the heart in the line of the interauricular septum beginning at the site of the transverse sinus behind the aorta and coming out posteriorly between the superior vena cava and the right pulmonary veins. With two, three, or four sutures placed through the heart in this way, pulled taut, tied together posteriorly, and then tied anteriorly Murray was able to compress the anterior wall to the posterior wall of the auricle in such a way as completely to occlude the experimentally produced defects in dogs. Using this method on a 12-year-old patient two sutures were placed and tied down which firmly compressed the anterior and posterior walls of the auricles. The right auricle diminished to at least one-half of its size within about two minutes. With this method there is a great danger of obstructing the superior vena cava or the right superior pulmonary vein. Furthermore a large defect or one close to the valvular plane cannot be completely occluded by the described method. Cardiac catheterization performed fourteen months postoperatively on this patient showed a substantial left-to-right shunt and significant right heart hypertension.

2. Swan and his associates in 1948 described a method by which both auricular appendages were invaginated and their tips firmly fastened together through the septal defect which was plugged by this maneuver. Large defects close to the valvular area cannot be occluded in this way, and an obstruction of the pulmonary veins may occur.

3. Söndergaard (1952) described the following method: A dissection was first carried out in the interauricular septal plane beginning between the superior vena cava and the right superior pulmonary veins, continuing downward between the inferior vena cava and the right inferior pulmonary vein. This dissection was carried between the left and right auricular wall until the point was reached where the muscle fibers crossed over from the right to the left auricle. When this groove between right and left auricle has been dissected, one suture is anchored in the right auricular wall at the base of the aorta just

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nants of an interauricular septum remained, and there was a communicating defect of the upper portion of the interventricular septum as well (verified at post-mortem examination).

When the sutures were drawn taut the hole between the auricles became smaller but a large communication still remained. The child died in connection with the operation.

This operation made the following points clear:

1. It is necessary to have a finger in the auricle (a) to exclude mitral stenosis or make a valvulotomy, (b) to exclude abnormal venous return, (c) to guide the needle, and (d) to ascertain an effective closure of the interauricular septal defect.

2. The Söndergaard method is not effective in cases when the interauricular communication is very large and when the defect is situated close to the valvular plane or combined with a high interventricular defect (atrioventricularis communis).

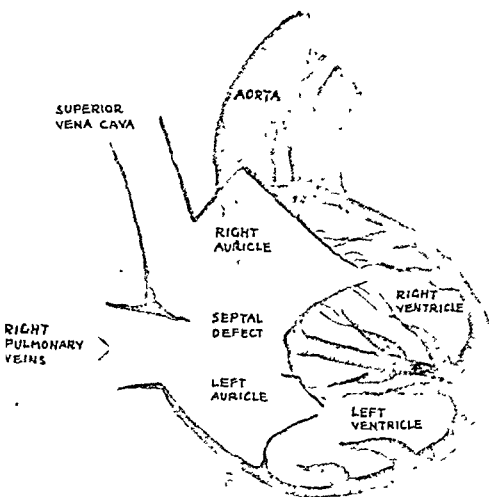


Fig. 1.

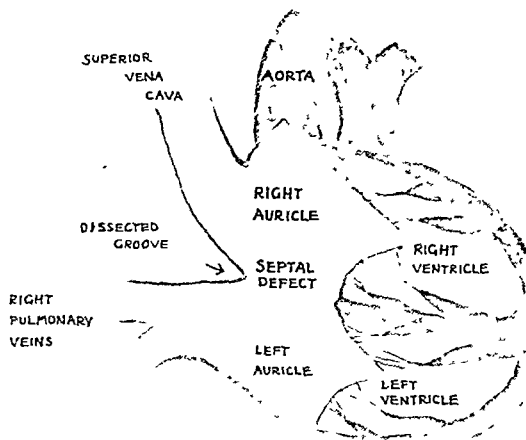


Fig. 2.

Fig. 1.—Diagram of the heart in a patient with a large interauricular septal defect in continuity with the bicuspid and the tricuspid valves.

Fig. 2.—Diagram of the dissection between the right and left auricular wall which is continued until the muscle bundles from the two auricles cross from one side over to the other as a network (according to Söndergaard).

On an autopsy specimen the following method was worked out:

A. The pericardium is opened in front of the right phrenic nerve. The superior and inferior vena cava are dissected free at their entrance in the right auricle. Then a dissection between the superior vena cava and the superior pulmonary vein is performed. This dissection is continued down between the right and left auricular wall until the muscle bundles from the two auricles cross over from one to the other as a network (Figs. 1 and 2). The dissection

2. In 1952 Gross and his fellow workers published a report of an ingenious method using an atrial well. They attached temporarily a cone-shaped rubber bag to the right auricular wall so that the auricle could be opened and blood allowed to rise up into the rubber "well." Through this column of blood it was possible to pass a finger down into the auricle, to find the septal opening and to close it either by direct suture or by the onlay of a piece of flat substance such as fascia, pericardium, or plastic. Six cases were reported, two with a successful outcome. This method contains a new principle for intra-auricular tactile surgery. It may be used in combination with any type of closure of the defect, even if the defect is a very large one.

3. During 1952 Swan reported successful results with a modified method. With a finger placed in the right auricle, a ligature probe is passed from the left auricular appendage through the septum at the edge of the defect out on the right side along the finger, and a thread is pulled through. This is repeated at the other edge of the defect. The threads are tied to a plastic button which is pushed into the right auricle as the sutures are pulled up taut. The button lies in the right auricle over the defect. When the sutures are tied over another button, the left auricle is inverted against the first button in the defect. It is suspected that this method would be difficult to apply in cases with large defects where no septal rim remains.

4. Hufnagel and Gillespie (1951) devised a method by which two plastic buttons, one on each side of the septum, were screwed together. It was essential to have a complete rim to hold the double button in place. Gross, with his associates, has clearly shown that this method is not safe in human beings (applied in three cases, all of the patients died), who are too likely to have incomplete rims around the opening and thus not sufficient substance to hold the buttons in place securely.

C. Open Method on Bloodless Heart.—

In 1951 Dennis and his co-workers used a pump oxygenator on a 6-year-old girl. For forty minutes the right auricle was open and a septal defect was closed under direct vision with interrupted sutures. The patient died. This method may be further developed, perhaps in combination with hypothermia, to provide safe intracardiac surgery under direct vision.

THE METHOD WE HAVE USED

The technique described by Söndergaard was applied during an operation on a 6-year-old girl with complete absence of the interauricular septum, a huge right auricle, and pulmonary hypertension (pulmonary artery pressure 73/40, mean 50 mm. Hg). As the two sutures were drawn taut the heart beat became weak and irregular. In order to find the reason for this reaction of the heart, a finger was introduced through the right auricular appendage. A complicating mitral stenosis (Lutembacher syndrome) not diagnosed beforehand was palpated. A digital dilatation of the mitral valve was easily performed from the right auricle. Palpation further revealed that only a small rim of septum remained in the superior portion of the auricles. No other rem-

negligible and therefore abandoned until palpation from the inside of the auricle has been carried out (In experimental animals with intact septum a considerable groove may be dissected between the inferior vena cava and the left auricle.)

The dissection between the superior vena cava and the pulmonary veins on the other hand is important in order to avoid an obstruction of these vessels when the suture is tied.

Fig 5

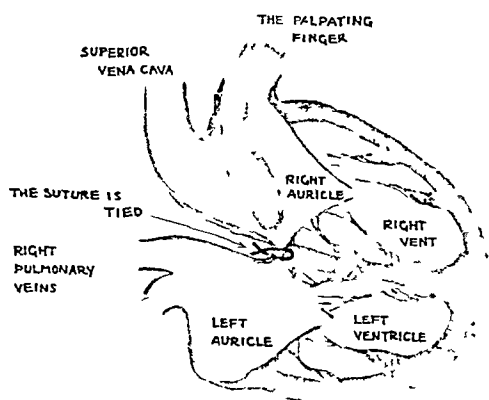
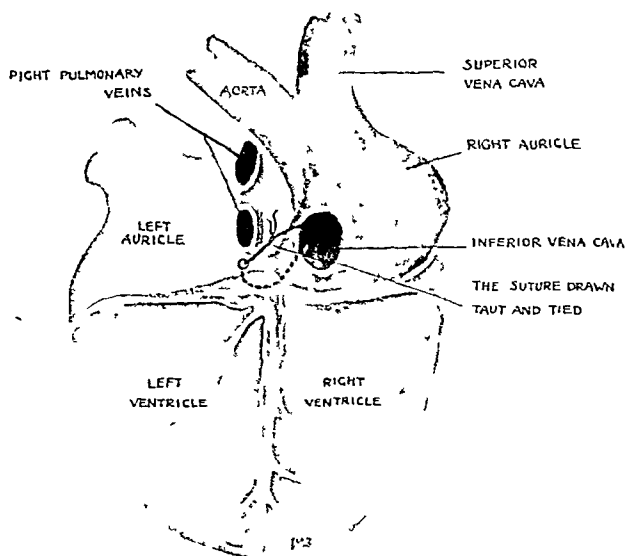


Fig 6

Fig 5—The suture is drawn taut and tied

Fig 6—The septal area between the venae cavae and the right pulmonary veins has then been encircled and anchored down to the interventricular septum

is continued down between the inferior vena cava and the left auricle. This dissection is the one originally described by Sondergaard in 1952. However, in cases with a large septal defect without a septal rim the dissection that can be carried out between the inferior vena cava and the pulmonary veins is

Fig. 3.

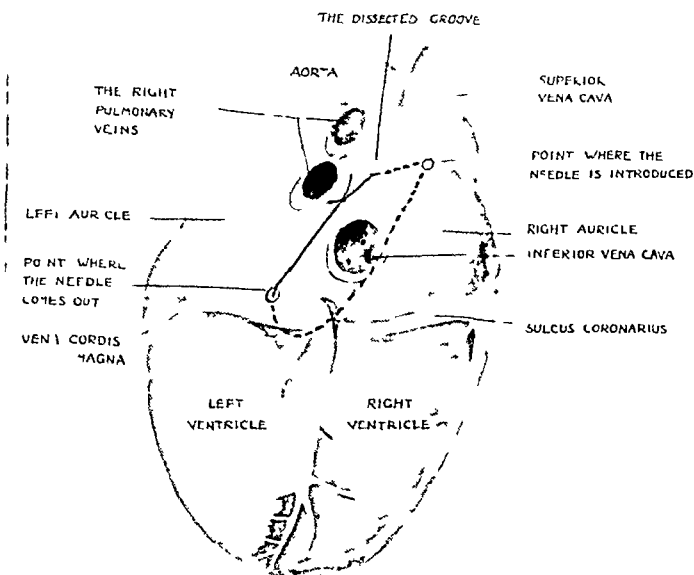
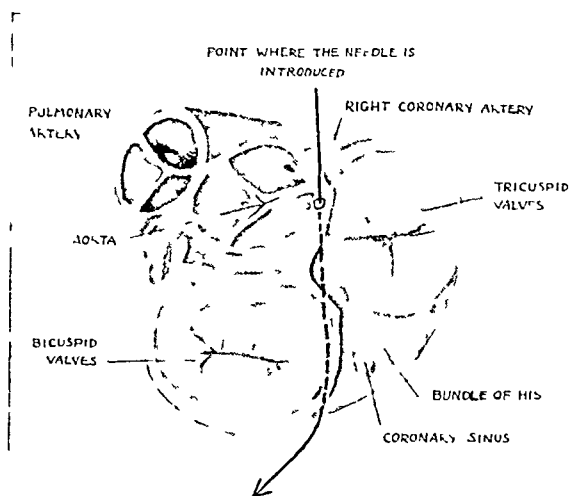


Fig. 4

Fig. 3—The needle is introduced through the right auricular wall at the right side of the root of the aorta behind the right coronary artery. The needle is then guided through the upper portion of the interventricular septum over to the left side and out through the left auricular wall behind the inferior vena cava.

Fig. 4—Diagram showing where the needle is introduced and taken out and where the suture is tied in the dissected groove between left and right auricle.

sity over third and fourth interspace. The second sound was divided. X-ray examination showed enlarged right ventricle and pulmonary artery. Heart catheterization (B. Jönsson) showed a large left-to-right auricular shunt (oxygen saturation in superior vena cava 58 per cent, inferior vena cava 67 per cent, right auricle 84 per cent, left auricle 97 per cent, right ventricle 85 per cent, and pulmonary artery 85 per cent) and a slightly increased pressure in the right ventricle (48/11, mean 24 mm. Hg) and the pulmonary artery (35/9, mean 18 mm. Hg).

Angiocardiography (Kjellberg) demonstrated an interauricular septal defect close to the valvular plane.

March 20, 1953, the right chest was opened through the bed of the sixth rib. The pericardium was opened in front of the phrenic nerve. The dissection between the superior vena cava and the superior pulmonary vein was continued until a considerable groove had been developed. At the bottom of the groove behind the superior vena cava a small arterial branch was divided and sutured. A finger was now inserted through the auricular appendage. Palpation revealed that only a small rim of septum remained at its superior margin. A needle was introduced to the right of the base of the aorta and guided subendocardially through the superior portion of the interventricular septum and out behind the inferior vena cava through the left auricular wall close to the interventricular plane. The suture was then drawn taut and tied over fibrin foam in the dissected groove. The septal defect had diminished in size from about 3 or 4 cm. in diameter to an oval opening with a maximum diameter of 0.5 cm. No obstruction of the vena cava and coronary sinus could be palpated. No heart irregularity was encountered. The postoperative course was uneventful and the systolic murmur had disappeared.

SUMMARY

A review is given of earlier techniques for the closure of interauricular septal defects.

A new method is presented the main features of which are:

1. A groove between the superior vena cava and the pulmonary veins is dissected (according to Söndergaard).

2. With a finger inserted in the auricle through the right auricular appendage a needle is guided subendocardially in the septal plane. It is introduced through the right auricular wall close to the root of the aorta just behind the right coronary artery. The needle follows the aorta down and through the upper portion of the interventricular septum. Through the posterior portion of the interventricular septum the needle should come over more to the left side and then come out through the left auricular wall behind the inferior vena cava, close to the annulus fibrosus. The two ends of the silk suture thus drawn through are tied in the dissected groove.

This method seems to be applicable even in cases with a very large interauricular septal defect without a septal rim. The application of the method on a patient with a large septal defect is reported.

ADDENDUM

Since this article was accepted two more patients have been operated on in the same manner with very good results.

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B. With the finger inserted through the right auricular appendage a long, thin, curved needle is introduced through the right auricular wall at the right side of the root of the aorta behind the right coronary artery (Fig. 3). The needle should follow the aorta as close as possible subendocardially. It must not enter the aorta and injure the posterior semilunar valve. Under digital guidance the needle should be directed subendocardially (in the rim of septum if one remains) down through the upper portion of the interventricular septum between the mitral and tricuspid valves and out through the auricular wall behind the inferior vena cava (Fig. 4). It may be impossible to predict if the needle will come out through the left or right auricular wall as a septum may be absent, but the palpating finger can direct the needle out behind the inferior vena cava in such a way that neither inferior vena cava nor the coronary sinus will be obstructed when the suture is tied. The two ends of the thread are then drawn taut over a piece of fibrin foam in the groove dissected between the superior vena cava and the right pulmonary veins (Fig. 5). With the finger inside the right auricle it can easily be determined how the septal defect diminishes concentrically until an effective closure is obtained. Then the suture is tied (Fig. 6). The septal area between the vena cava and the right pulmonary veins has then been encircled and anchored down to the interventricular septum excluding an interauricular communication.

Indications.—This method seems to be applicable in all different types and sizes of uncomplicated atrial septal communications of clinical importance.

It can also be applied in cases complicated with mitral stenosis and with an atrioventricularis communis.

Experimental Work.—In the experimental animal the anatomic and pathophysiologic changes encountered in large septal defects cannot be produced. Thus the experimental work is only of a limited value:

1. Applying the atrial well, described by Gross, we have produced interauricular septal defects and closed them in the above-mentioned manner for training purposes.

2. When the atrial well is sutured in place and the interauricular defect is produced, we have passed needles through the interventricular septum without heart irregularities or ECG changes. The anterior part of the interventricular septum may even be crushed between clamps without irregularities. If the posterior part of the upper portion of the interventricular septum (including the bundle of His) is crushed, irregularities are encountered. The bundle of His comes from the right auricle over on the right side of the posterior portion of the interventricular septum. It is therefore advisable to guide the needle over on the left side when it is passing through the posterior portion of the interventricular septum and take it out through the left auricular wall behind the inferior vena cava as close to the atrioventricular border and the interventricular septal plane as possible.

CASE REPORT

A 6-year-old boy could not play as other children. He had never been cyanotic. Physical examination revealed a short harsh loud systolic murmur with maximum inten-

THORACOABDOMINAL ECTOPIA CORDIS

REPORT OF A CASE SUCCESSFULLY TREATED BY SURGERY

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ECTOPIA cordis is a congenital anomaly in which the heart lies partially or totally outside the mediastinum. According to the literature, it is one of the rarest of anomalies. To date 142 cases have been reported.¹ Weese, in 1818, classified ectopia cordis in three groups: cervical, thoracic, and abdominal. Byron¹ has added a fourth category, thoracoabdominal.

This paper attempts to summarize the latter group and reports in detail one case successfully treated by surgery. Also, brief mention will be made of four additional cases of this type of anomaly which have not yet been reported,²⁻⁵ but which were surgically treated.

Table I is a summary of the known cases of ectopia cordis. None of the cervical group has been treated surgically, but at least one patient⁶ survived to adulthood with the heart apparent in the left upper thorax and neck. In the thoracic group, three patients underwent some type of surgery without success.^{1, 7, 8} One patient with an abdominal defect died after surgery,⁹ although in this group there have been survivals to adulthood. In the thoracoabdominal group, at least five cases have been treated surgically, two with apparent success.⁵ In at least one other case of this latter group,¹⁰ there is a possibility that had surgery been carried out at birth, the outcome might have been different. This belief will be enlarged upon when the case is quoted.

In thoracoabdominal ectopia cordis, three distinct defects of development are present in almost all cases: (1) partial absence of, or cleft of, the sternum, (2) diaphragmatic defect, (3) midline abdominal defect of diastasis recti or omphalocele type. The heart is partially displaced into the defect and may have complete, incomplete, or no pericardium. Depending upon the size of the herniation, abdominal viscera are also found in the protrusion. Other anomalies, such as harelip, cleft palate, cardiac and great vessel anomalies, anencephaly, clubfoot, etc., may be present and may influence the survival of the infant.

Embryologically, both heart and diaphragm arise in the cervical region, and descend during the fifth to the tenth week of gestation. The defects leading to the ectopia are apparent as early as the sixth or seventh week of development. They probably represent inherent abnormalities in the germ plasm with no relationship to the health of the mother or father, duration and complications of pregnancy or delivery. One can only speculate on the mechanism by which this disarrangement is produced.

The sternal defect apparently occurs because of the failure of the rib ends to fuse properly. The defect may range from complete lack of the sternum

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CASE 3.—Greig¹² quoted Breschet who described “an anencephalic foetus, cleft from the xiphoid to the umbilicus; the hernial sac contained abdominal and thoracic viscera. Into the upper part of this split projected the heart in its membranes, the horns of the thymus and the extremity of the inferior lobe of the left lung, the diaphragm being split behind the xiphoid process.”

CASE 4.—Greig¹² included this case report also. “In the seventh month foetus described by Pinelli, the heart without pericardium lay in the epigastrium where it and the abdominal viscera were only covered by peritoneum. The sternum, mediastinum and left lung were absent.”

CASE 5.—Greig¹² wrote “of Fleischmann who, in 1810, described a foetus in whom the sternum was so short that only the first ribs reached it. A prominent sac reached to the hypogastrium and contained in its upper part the heart which had passed through an opening in the diaphragm and outside the pericardium and appeared to be covered only by peritoneum.”

CASE 6.—This case was also mentioned by Greig.¹² “The heart of a premature female foetus . . . as mentioned by Sandifort, had passed through the diaphragm and rested in a hollow in the liver surface and the assumption of the same position is recorded by Wilson. This child was born at full term and died seven days later of septic inflammation due to sloughing of a membranous sac which protruded from the abdomen between the xiphoid process and the umbilicus. The child was of normal colour though at birth and for a short period before its death the lips occasionally had something of a livid appearance. During life the sac referred to contained a mobile tumour which on autopsy was found to be the heart. It was in the epigastric region and lay ‘in a cavity formed on the superior surface of the liver’ which was not divided by the falciform ligament but was hollowed out there to receive the heart. The tendinous portion of the diaphragm and the corresponding part of the pericardium were absent. . . . The heart was two chambered. A large arterial trunk arose from the ventricle and divided into aorta and pulmonary artery.”

CASE 7.—Greig¹² also referred to the following case. “There was no deficiency of the sternum or of the chest wall in the male aged 5 months in whom an umbilical hernia noticed at birth was found to contain a hard pulsating body. Holt states that the child was above average weight, but had some cyanosis during the first week of life. The recti muscles were widely separated above the umbilicus, and at the center of the protrusion a circular two-inch area was covered only by membrane at the lower edge of which was the umbilicus. A finger could be passed under the heart and its apex raised. A loud systolic murmur heard all over the heart but most distinctly at the left of the xiphoid, probably indicated along with the cyanosis a congenital septal defect.”

CASE 8.—Greig¹² mentioned, “Much the same condition [as in Case 7] obtained in a full-term child who only survived birth fifty-one hours, but the case is not very fully reported by Wintsch.”

CASE 9.—H. Imes¹⁰ described an infant born at term in which “a pulsating mass was noted in the epigastrium. This was raw and bright red. Soon after birth a scab formed, which came off and was replaced by another smaller scab at each dressing. After four weeks the mass became covered with skin. Cyanosis was not observed in the infant. She developed normally. . . . At 14½ months . . . developed empyema and died.” At autopsy “The sternum measures 6 cm. in length. There is no xiphoid process present. The costal angles and the curves of the costal margins are quite normal. Beginning at the lower end of the sternum and extending toward the umbilicus is a hernia-like swelling, 5 cm. in length and about 3 cm. wide. Within the swelling is felt a pear-shaped mass of firm consistency. The mass is somewhat movable, is rounded laterally, bluntly pointed at the lower end and becomes constricted at the upper end as it passes under the costal margins and lower end of the sternum. . . . There is a normally placed pulmonary artery and aorta, and

TABLE I. DISTRIBUTION BY SITE OF DEFECT

SITE	NUMBER
Thoracic	81
Abdominal	38
Combined thoracoabdominal	15
Cervical	4
Unclassified	9
Total	147

to the simple absence of the ensiform process. The diaphragmatic defect consists of a V-shaped aperture in the anterior diaphragm; the top of the "V" is defined by attachment to the edges of the sternal defect and the base by attachment to the vertebrae. The abdominal defect is midline, and varies from simple diastasis recti to complete omphalocele; it may be only epigastric or it may extend from the sternal defect to, or include, the umbilicus. In some instances it is completely covered by skin, while in others the main portion of the abnormality is covered only by a transparent membrane which is gelatinous in appearance, and probably represents pericardium, peritoneum, omphalic tissue, or a combination of these.

In the majority of cases reported, there have been patent interventricular or interauricular septal defects, and in some there have been other defects such as the tetralogy of Fallot, trilocular and bilocular hearts, pulmonic stenosis, abnormalities of the vena cava, and aortic anomalies.

The problem, therefore, is to correct any deformity which is incompatible with life. First, it is necessary to obtain a suitable skin covering for the heart and abdominal viscera, and second, these viscera, particularly the heart, must be placed so that their function will maintain life. It is believed that, in the case previously mentioned in which surgery might have been done, the growth of the child may have caused constriction of the heart by the diaphragm, indicating that perhaps not only the immediate but future action of this organ must be considered in any attempt at repair.

A summary of all known cases of thoracoabdominal ectopia cordis follows:

CASE REPORTS

CASE 1.—Willius¹¹ quoted an article written by Niels Stensen about 1680 which described a monster. "The lower part of the sternum consisted of cartilage and was connected with the rest of the sternum merely by a narrow union. As far as that goes, the sternum was split, and the heart, liver, spleen, most of the intestines and the right kidney had passed out through the slit, being thus uncovered. The lungs were in the thorax."

CASE 2.—Greig¹² cited O'Connor's 1861 report of a newborn infant in whom "there was deficiency of the abdominal wall and the protruding peritoneum was adherent to the placenta, the umbilical cord being only 4 inches in length. The distal part of the body of the sternum and the corresponding costal cartilages were deficient, and the heart was quite visible lying anterior to the chest wall. The child made no attempt at respiration, but the heart beat with considerable force. The heart-beats diminished in strength during a quarter of an hour; O'Connor then opened the pericardium and the heart-beats became stronger until they gradually ceased two and a half hours after delivery."

especially hypertrophied. There are features about the septum and appearance of the foramen ovale that may indicate that the foramen served for the passage of blood from the left to the right auricle. The right auricle and right ventricle and the passage between them are relatively very large. Finally, the defect in the interventricular septum is so placed that during systole of the ventricles blood from the right ventricle would appear to pass with about equal facility into the conus arteriosus (infundibulum) or into the aortic vestibule. It is into the latter, and not into the displaced left ventricle cavity, that the septal foramen opens. In the aortic vestibule, blood coming from the right auricle through the interventricular septal foramen would meet and mingle with blood from the left auricle, by way of the mitral orifice, coming under similar pressure from the left ventricle. Thus the deficiency in size of the left ventricle would be compensated for by the assistance of the right ventricle."

This is the case previously mentioned in which the possibility of constriction of the left ventricle by the diaphragm, or some part of the hernial ring, seems to have so embarrassed the circulation that at best the child was handicapped, possibly enough to lead to intercurrent infection and death. This leads to the speculation that had the difficulty been correctible and corrected, would the child have had a greater chance of survival?



Fig. 2—Infant reported by Ehrenhaft (Case 11).

CASE 10.—Kühnel¹³ cites a case in which "from the anterior surface of the heart a very thin cord is seen to extend down to the amniotic membrane of the umbilical cord; on microscopic examination this cord is found to consist of amniotic tissue.

"The slit itself is a combined abdomino-thoracic defect, the abdominal part of which is rather wide (measuring 5.6 cm. in width), but not open, being covered by a very thin membrane, which is found microscopically to be made up of two leaves, an inner peritoneal leaf and an outer amniotic membrane. The skin ceases on both sides of the distal angle of the defect, defined sharply by a low wall on each side. . . . Only the upper three ribs are connected to the sternum, while the rest are converging toward the margin of the skin, where they end freely." The heart was covered with warm saline sponges but the child died with cyanosis twenty-six hours after birth.

CASE 11.—Ehrenhaft² operated upon a 38-hour old white female infant on June 27, 1931, who at birth showed "a large dehiscence of the upper mid-abdominal wall from the umbilicus up to the area of the lower sternum. There was a dehiscence of the musculature

a right and left ventricle. What appears to be the anterior coronary artery passes almost straight downward in front. To the right of this lies a somewhat globular mass, resembling a rounded and hypertrophied right ventricle; to the left, a prolongation of this muscular mass extends downward and becomes continuous with the extra-thoracic tumor mass that has already been described. The whole forms an irregularly shaped heart, *the extra-thoracic tumor representing the bulk of the left ventricle.*

"The displaced portion of the heart lies, as is seen, below the rounded muscular mass that represents the right ventricle, and to the left of it. At the normal position of the apex there is a constriction in the muscular mass. This was perceptible to the palpating finger before section; below this the mass expands to form the extra-thoracic tumor. . . .

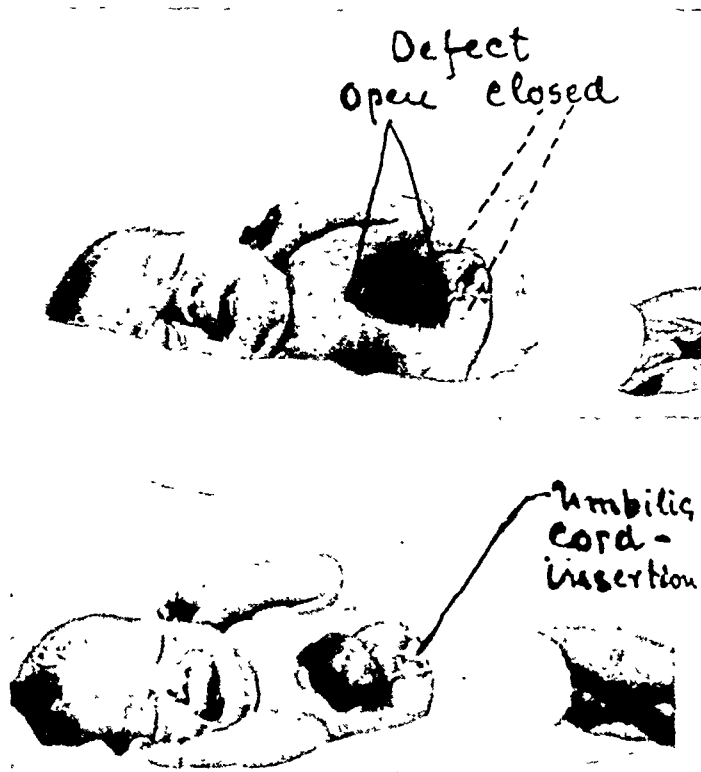


Fig. 1.—Photograph of infant described by Kühnel in Case 10. (From Kühnel: *Acta obst. et gynec. Scandinav.* 20: 128-137, 1940.)

"Examination of the diaphragm, as a whole, shows that it is normally placed, normal in its contour and normal in its attachments, except that, symmetrically on the two sides, it leaves the costal margin near the median line and, curving downward, finds its attachment in the fascia of the abdominal wall, as low as 5 cm. below the level of the costal angle. . . .

"In considering the character of the circulation in the heart just described, certain facts seem to be of especial importance. Among these are the following:

"The left ventricle is relatively small, and to a considerable degree is detached from the main body of the heart. The mitral orifice is small, so small as to suggest that it played a less than normal part in the transmission of blood from the left auricle (pulmonary circulation) to the systemic circulation. The walls of the left auricle are not

Under drop ether anesthesia an incision was made in a complete circle just outside the skin margin and dissection was carried down to the abdominal fascia and onto the rib and sternal fascia; care was taken to preserve intact the peritoneum and associated membranes. When the fascia had been cleaned and adequately exposed, attention was turned to the urachus and hypogastric vessels, which were dissected free and tied off. Extending from the pulsating mass in the upper portion of the defect, was what appeared to be a large pulsating vessel about 1 cm. in diameter. At first this was thought to represent the umbilical vein. However, the liver, which was prominent beneath this, was then visualized through an opening in the peritoneum and the umbilical vein located to the right. This was tied off and transected. Following this, the liver could be pressed into the abdominal cavity, and obviously there was no connection between it and the heart with its pulsating extension. This extension appeared to fuse with the central portion of the previously



Fig. 4.—Baby M. A. K. at the age of one month.

described membrane, and although now thought to be some anomaly of the inferior vena cava, it led only into the peritoneal covering. It was dissected free and tied off without ill effect. When transected it was found to be only a serous membrane, and therefore was only an extension of the parietal pericardium. The heart could be placed into the defect and flush with the anterior body wall. When this was done a V-shaped defect in the diaphragm was seen at the lateral edges of which were the lower margins of each lung, covered by pleura. When, by lateral pressure, the defect was closed, the heart rested in the diaphragmatic defect, and the liver rested beneath it. The child stood this maneuver satisfactorily. Therefore, excess peritoneum was removed, and with the assistant maintaining bilateral pressure, the peritoneum and fascia were closed with interrupted sutures of 0000 cotton. In the upper portion between the ribs, and at the level of the sternal defect, a fascial covering could not be made, and only the skin was closed. The assistant's pressure was maintained while a dressing was applied, which completely encircled the patient with strips of adhesive tape. The child was slightly cyanotic, but respiratory and cardiac action were strong, and she was returned to the nursery where oxygen was given for three days. Subsequent development has been entirely normal. Electrocardiograms

and intestines as well as liver in the lower portion and heart in the upper portion . . . covered only by a very thin membrane. . . . During the dissection it became evident that the heart where it came through a rent where the diaphragm had failed to fuse with the anterior chest wall . . . presented mostly ventricle . . .” To gain more room the surgeon resected some of the costal margins and lower sternum, but none of the procedures were successful. The child survived the operative procedure but died about forty-five minutes later. Permission for post-mortem examination was obtained. It was discovered that the child had a tri-chamber heart with a single ventricle. Obviously this was not compatible with any length of survival.

CASE 12.—Dr. Murray L. Johnson³ repaired a case of thoracoabdominal ectopia cordis in 1950; the child survived twenty-four days. This case is to be reported in detail by Dr. Johnson in the near future.

CASE 13.—Dr. Harris B. Schumacher⁴ also attempted the repair of a case of this group in 1948, but the child did not survive the procedure. In this case, as in Hofman's, there was a constriction about the ventricles, as Dr. Schumacher will show when he reports the case.

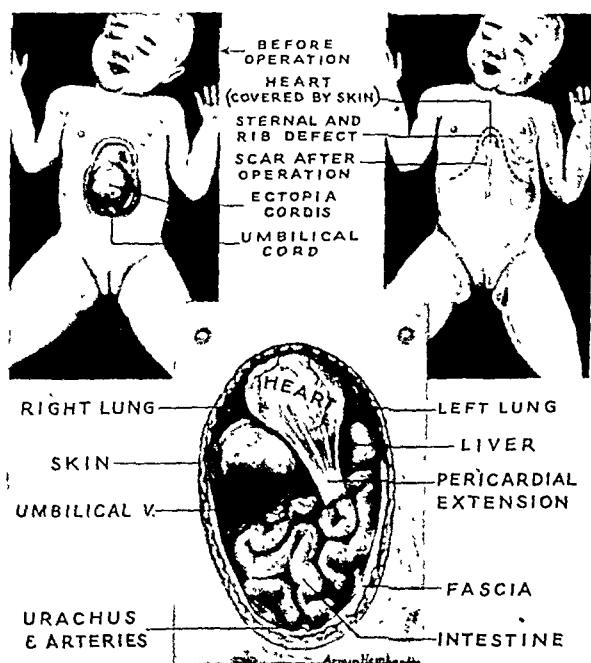


Fig. 3.—Baby M. A. K. at birth.

CASE 14.—This child, M. A. K., was delivered routinely on Oct. 2, 1951, and weighed 8 pounds, 14 ounces. She breathed and cried readily, and was quite vigorous. However, there was mild cyanosis and a defect of the anterior abdominal wall and thoracic cage. Normal skin extended from the circumference up onto the defect for approximately 1 cm. The intervening space, which was about 5 cm. wide and 8 cm. long, was covered only by a thin, translucent membrane, presumably peritoneum and pericardium. The upper one-third of the defect was occupied by a pulsating mass. At the time of operation, it was estimated that about one-third of the heart protruded above the level of the thoracic cage. The heart sounds were normal. Immediate surgery was decided upon.

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and chest x-rays were within normal limits, and no other anomalies have manifested themselves. The child is now one year old, weighs 24 pounds, and is normal for this age. The pulsations of the heart have continued to be visible beneath the skin and palpable in the region of the sternal defect and epigastrium. The defect seems proportionately smaller than it was at one month of age.



Fig. 5.—Baby M. A. K. shown at the age of one year.

CASE 15.—Since the writing of this paper it has been learned that Dr. Mark Ravitch⁵ has had a successful repair of this anomaly in a 20-year-old patient, and will report the case. (This case has been added to Table I by the courtesy of Dr. Ravitch.)

SUMMARY

A brief summary of the literature on ectopia cordis has been given, with clinical briefs of all known cases of the thoracoabdominal type. A detailed account is given of one such case which has been successfully treated by surgery. The patient is now alive and well at the age of 12 months.

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Fig. 1.—Massive pleural effusion (chylous) on left side.



Fig. 2

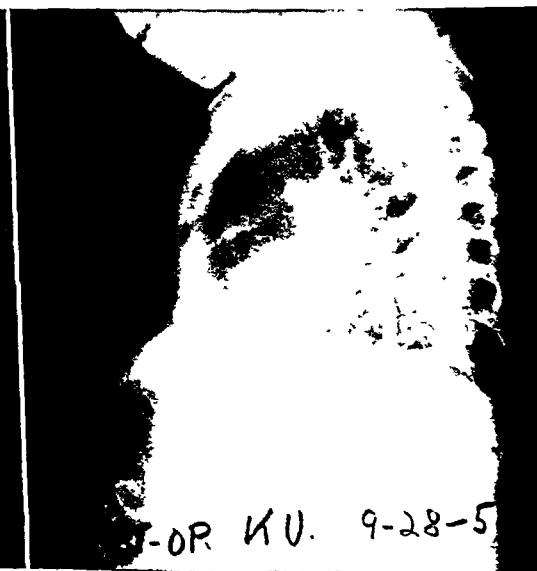


Fig. 3.

Fig. 2.—Lung completely re-expanded. No fluid in pleural cavity.

Fig. 3.—Lateral view to show iodized oil in mediastinum. Pleural cavity free of fluid.

CHRONIC CHYLOTHORAX ASSOCIATED WITH HYGROMA OF THE MEDIASTINUM

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THIS case report is presented to demonstrate a satisfactory method of handling a patient with chronic chylothorax.

K. U., a 3½ year old boy, was admitted to Mount Sinai Hospital on April 4, 1950, for the treatment of a left chylothorax. At birth it was noted that the boy had a cardiac murmur, funnel chest, and incomplete separation of the toes. Following a respiratory infection at the age of 4 months, growth and development were poor. One month prior to admission he had been in another hospital where a diagnosis of chylothorax was made by physical and roentgenographic examinations and thoracentesis.

Physical examination revealed a feeble dyspneic child, with marked sternal retraction and dullness and diminished breath sounds over the entire left chest. A harsh systolic murmur was present over the entire precordium. Abdomen was distended, liver and spleen were both enlarged. Laboratory examination was noncontributory.

Hospital Course—Repeated thoracenteses were quickly followed by reaccumulation of chylous fluid containing a preponderance of lymphocytic like cells. Although mediastinal tumor was considered in the differential diagnosis, an x-ray film following accidental pneumothorax ruled this out. Fig. 1 demonstrates the preoperative status. Thoracotomy was suggested and carried out on June 7, 1950.

Findings and Operative Procedure—The left chest was entered through the seventh intercostal space by a liberal posterolateral incision. The chest was filled with chylous fluid which was evacuated with suction. In the region of the lower end of the esophagus, just above the diaphragm, there was noted a leakage of chylous fluid. The mediastinal pleura was incised at this point and a number of dilated lymph ducts were noted, one of which extended along the diaphragm and onto the pericardium. These ducts were clamped, divided, and ligated. Extending upward along the aorta there was a large tumor like mass which consisted of distended lymphatic ducts containing chyle. This tumor like mass was dissected free from the aorta to which it was intimately adherent. The intervening channels were ligated as they were dissected free. After ligating all these various channels it was noted that there was still leakage of chyle in the region of the lower end of the esophagus. A number of ductlike openings were noted and ligated and by dissecting in and around the esophagus and the region between the esophagus and the aorta, a cloaca like structure was dissected out, which occupied the mediastinum. The opposite pleura was deliberately entered to see if there was any leakage of chyle from the opposite side, but there was none and the pleura was closed. Because it was impossible to remove this entire lymphatic channel which really consisted of the mediastinum rather than one single duct, Lipiodol (about 5 cc) was injected into this region and the mediastinal pleura closed over loosely. The chest was closed in layers after a catheter drain had been inserted through a lower intercostal space. Penicillin (200,000 units) was instilled into the pleural cavity. Chronic and plum catgut were used throughout.

The postoperative course was characterized by gastric and intestinal dilation which responded to conservative measures. Three weeks after the operation the left chest was entirely clear and there was no reaccumulation of fluid. Figs. 2 and 3 show the postoperative status with Lipiodol in situ.

TRAUMATIC CHYLOTHORAX FOLLOWING ESOPHAGEAL RESECTION

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TRAUMATIC chylothorax was first described, according to Olsen and Wilson,¹ by Bartelot in 1633. There have only been sixty-nine cases reported in the literature to date. However, this does not mean that this condition is as rare as the paucity of reports would seem to indicate. With the great increase in intrathoracic surgical procedures in the past fifteen years, it is probable that this condition is met with more frequently.

EMBRYOLOGY AND ANATOMY OF THE THORACIC DUCT

The lymphatic system is closely related to, and developed concurrently with, the venous system. Sabin² believes that all lymphatics are developed as outgrowths of venous endothelium in six situations: two paired in the neck region, two paired from the iliac veins, and two unpaired, the retroperitoneal sac and the cisterna chyli. By continuous centrifugal growth and branching, lymphatic channels invade most tissues of the body. The original connections may be retained as the definite connections of the adult lymphatic system, or may disappear and become re-established later. Kampmeier³ and Huntington,⁴ on the other hand, believe that the lymphatic system arises by the confluence of perivenous mesenchymal spaces to form larger spaces which in turn become confluent to form continuous vessels which eventually open into the venous system. The cells lining the spaces are at first undifferentiated mesenchyma, but later become flattened to form the endothelium of the lymphatic vessels.

In the human embryo the lymphatic spaces which represent the beginning of the definite lymphatic system appear in the jugular region of each side and coalesce to form the jugular lymph sacs at the 10 to 11 mm. stage. The jugular lymph sacs become closely associated with the lymphatics of the arm bud. The upper part of the thoracic duct, on each side, is formed from these lymph sacs. These channels become secondarily connected with the developing cisterna chyli to form paired thoracic ducts.

There are many variations in the anatomy of the thoracic duct.^{5, 6} The duct varies from 4 to 6 mm. in diameter. Its length is 38 to 45 cm. It usually arises in a roughly triangular body, the cisterna chyli, which lies on the anterior surface of the second lumbar vertebra, posterior to, and to the right of, the aorta. The cisterna is the receptacle for all lymph from the lumbar area and intestines. Just above the cisterna, on either side, and emptying into it, are bilateral descending vessels which drain the lower six or seven intercostal spaces. The thoracic duct extends upward along the right side of the aorta. It traverses the diaphragm through the aortic hiatus between the azygos vein and aorta. The duct usually deviates to the left at the level of the fifth dorsal vertebra. The ascent continues behind the arch of the aorta and subclavian artery to the root of the neck where it may rise as high as 5 cm. above the clavicle. It then crosses in front of the subclavian vessels and empties into the left innominate vein at the angle of union of the left subclavian and left internal jugular veins.

From the Department of Thoracic Surgery, Metropolitan Hospital.
Received for publication Feb. 20, 1953.

The pathology report on the specimen was hygroma and lymph nodes showing sinus endothelial hyperplasia.

Follow-up Report.—On Sept. 25, 1950 (three months after the operation), the boy was readmitted because of an acute bronchitis and bilateral otitis media. The chest remained clear. A recent follow-up letter states that the boy is perfectly well and there has been no recurrence of the left pleural effusion. (It has been two years since the operation.)

DISCUSSION

The use of sclerosing solutions to produce a chemical pleuritis was popularized by Hennell¹ who used concentrated glucose solutions in the treatment of chronic tension pneumothorax. Concentrated (67 per cent) glucose can be followed by Lipiodol for a more severe and lasting effect. Lipiodol in this instance, by producing a plastic fibrinous exudate, sealed over the remaining openings in the chyle duct after the main hygroma had been excised and the major channels closed by suture or ligation. Thus a new adjunct is added in the treatment of chylothorax. Since the presentation of this report we have had experience with a case of traumatic chylothorax successfully cured by glucose instillations and chest aspirations.

The case presented also illustrates an additional variant in the etiology of spontaneous chronic chylothorax.

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Fig. 1.



Fig. 2.

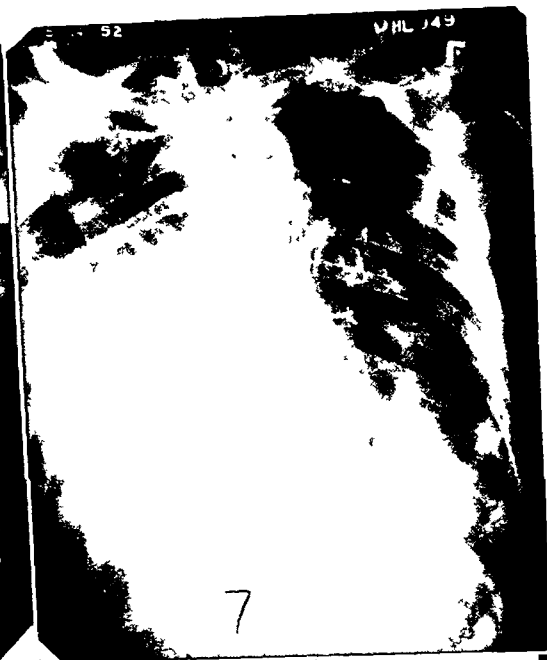


Fig. 3

Fig. 4

Fig. 1—Preoperative roentgenogram showing defect in the mid-esophagus

Fig. 2—Postoperative roentgenogram showing the patent anastomosis between esophagus and stomach high in the left chest and right hydrothorax (chylothorax).

Fig. 3—Roentgenogram showing increase in the right chylothorax

Fig. 4—Roentgenogram showing complete re-expansion of the lung prior to removal of the intercostal catheter.

PATHOLOGIC PHYSIOLOGY

Normally approximately 130 to 190 c.c. of chyle pass through the duct hourly.⁷ Inanition and dehydration rapidly follow untreated chylothorax. The albumin depletion is most rapid and severe since the lymphatic system collects albumin from all the interstitial spaces of the body.

There are several possible mechanisms for the production of chylothorax. According to Hammesfahr, as quoted by Watts,⁸ chyle escapes into the pleural cavity upon injury of the thoracic duct through normal intercellular spaces between the endothelial cells. Lillie and Fox⁹ quoted Yates to the effect that there are no intercellular spaces in this region and that a perforation of the pleura is always present although it may not be recognized. Blalock, Cunningham, and Robinson,¹⁰ in their work on superior vena cava "tie offs," state that chyle enters the pleural cavity through an uninjured pleural layer. Perhaps the delay in the presenting symptoms is due to the retropleural accumulation of chyle which eventually erodes the adjacent pleura changing the chyloma into a chylothorax.

DIAGNOSIS

Signs and symptoms of chylothorax are mechanical in nature and depend upon the space-occupying effect of the accumulated fluid upon the lung and mediastinal structures. Chylothorax is more common on the right than on the left, except in cases of penetrating injuries where the hemithorax involved will depend upon the level of the penetrating wound. It will involve the right side in lower injuries and the left side in higher injuries. There is a drop in the eosinophil and lymphocyte counts, factors of some diagnostic importance. Klepser¹¹ suggests the following method as an aid in diagnosis. The patient is fed fat which contains a lipophilic coal tar dye, such as Sudan III. Within two hours the chyle becomes colored by the dye.

TREATMENT

The principles of treatment fall under four headings, and consist of reduction in the volume of chyle loss; maintenance of an expanded lung; prevention of infection, and maintenance of nutrition. Conservative management should be tried first. This consists of repeated thoracenteses or continuous closed drainage by an intercostal tube to keep the hemithorax free of fluid and the lung expanded. Usually these measures will suffice and a spontaneous closure of the chyle fistula will occur. However, if, after an adequate trial at conservative treatment has failed, more definite measures should be tried. This consists of the ligation of the duct. Collateral chyle channels are soon established.

We are reporting the following case of traumatic chylothorax subsequent to a resection of the esophagus for carcinoma. The chylothorax responded to conservative treatment.

CASE REPORT

A. B., a 49-year-old Negro man, was admitted to the Metropolitan Hospital on April 7, 1952, with symptoms of dysphagia of one month's duration. At the onset he could not swallow solid foods without "washing down" with water. Over the ensuing four weeks, the difficulty in swallowing became worse; it became increasingly difficult to swallow soft foods and finally liquids. There had been a fifteen pound weight loss during this time. The physical examination revealed no positive findings except the evidence of recent weight loss. Esophagram revealed irregularity and narrowing in the mid-third of the esophagus. At esophagoscopy, a fungating mass was visualized. A biopsy of this mass showed epidermoid carcinoma.

LOCALIZED PLEURAL MESOTHELIOMA OF EPITHELIAL TYPE

RAYMOND YESSER, M.D.,* AND ALFRED HURWITZ, M.D.**
NEWINGTON, CONN.

STOUT and Murray¹ emphasized the fact that pleural mesotheliomas were either diffuse or localized. Diffuse tumors are characterized by the presence of both epithelioid and spindle cells. The localized type do not have epithelioid elements but resemble a fibroma or fibrosarcoma because of the presence of spindle-shaped cells only. Mesotheliomas may grow to a large size, but rarely metastasize to distant organs. Most of these tumors are confined to the pleura but some infiltrate surrounding tissues. Hochberg² contended that they were all malignant and should be treated by radical pneumonectomy and pleurectomy whenever possible.

There are four main theories concerning their origin: (1) that they are secondary to occult primary cancers; (2) that they are derived from the endothelium of lymphatic vessels; (3) that they are an outgrowth of remnants of pulmonary epithelial tissue left during embryonic life; and (4) that they arise from the pleural mesothelial cells. The last hypothesis is the commonly accepted one. Clagett³ has agreed with Klemperer and Rabin⁴ that the localized mesotheliomas originate from the tissue beneath the superficial lining cells of the pleura in contradistinction to the diffuse form which arises from the surface lining. In Clagett's series of twenty-four cases of localized fibrous mesotheliomas of the pleura, the histologic study revealed that all the tumors were composed of spindle cells which produce collagen intercellularly. The following case showed a localized pleural lesion with unusual histologic features.

CASE REPORT

A 25-year-old, well-developed, white man was admitted to the hospital on May 31, 1951, because of a left hilar mass discovered on routine chest x-ray examination.

Physical examination revealed depressed scars on the cheeks with a single, firm, non-tender node in the angle of the left jaw. On the right forearm and left shoulder there were noted several small, irregular, brown patches which were not raised and did not blanch on pressure. Clubbing of the fingers was not present.

X-ray views of the chest revealed a rounded, sharply delineated mass in the left hilar region (Fig. 1), located in the posterior mediastinal area. Angiogram demonstrated that the lesion could be separated from the vascular channels.

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At operation on April 28, 1952, through a left thoracotomy approach, a very hard, elongated mass occupying the esophagus (extending from the aortic arch to approximately $3\frac{1}{2}$ inches caudad) was encountered. The esophagus was adherent to the left main-stem bronchus. In mobilizing the esophagus a sucking sound was heard, and it was recognized that the right pleural cavity had been entered. The thoracic duct was not recognized during the dissection. A resection of the esophagus with a supra-aortic esophagogastric anastomosis was effected. The patient withstood the operative procedure well. Fluid was noted in the right chest on the first postoperative day but this was not unexpected as the right pleura had been entered during the operation. On the second postoperative day 1,500 c.c. of dark bloody fluid was withdrawn from the right hemithorax. This fluid was undoubtedly an admixture of blood and chyle which went unrecognized as chylothorax. On the tenth postoperative day the patient became markedly short of breath and there was radiographic evidence of almost complete right hydrothorax. Thoracentesis yielded 3,000 c.c. of thick milky liquid. For the next six days daily thoracenteses yielded from 2,300 to 3,000 c.c. of the same type of fluid. It was then decided to use constant suction drainage and this was accomplished by inserting a No. 16 catheter by the trocar-cannula method through the seventh intercostal space, laterally. Almost immediately there was a lessening of the drainage and after four days the chyle drainage ceased entirely. There was complete re-expansion of the lung. The catheter was then removed. From this time on, the course was uncomplicated. The patient was able to swallow a regular diet well.

The patient has been followed with monthly esophagoscopy for the past 10 months. There has been no evidence of recurrence of the tumor and weight gain has been satisfactory. Barium studies show an elongated stomach in the left chest with a wide stoma at the level of the second interspace anteriorly.

CONCLUSION

We have reported a case of traumatic chylothorax due to unrecognized trauma to the thoracic duct sustained in the course of mobilization of the esophagus preparatory to its resection for carcinoma. There was an excellent response to the conservative regimen employed, namely, repeated aspirations and constant suction drainage.

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LOCALIZED PLEURAL MESOTHELIOMA OF EPITHELIAL TYPE

RAYMOND YESNER, M.D.,* AND ALFRED HURWITZ, M.D.**
NEWINGTON, CONN.

STOUT and Murray¹ emphasized the fact that pleural mesotheliomas were either diffuse or localized. Diffuse tumors are characterized by the presence of both epithelioid and spindle cells. The localized type do not have epithelioid elements but resemble a fibroma or fibrosarcoma because of the presence of spindle-shaped cells only. Mesotheliomas may grow to a large size, but rarely metastasize to distant organs. Most of these tumors are confined to the pleura but some infiltrate surrounding tissues. Hochberg² contended that they were all malignant and should be treated by radical pneumonectomy and pleurectomy whenever possible.

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CASE REPORT

A 25-year-old, well-developed, white man was admitted to the hospital on May 31, 1951, because of a left hilar mass discovered on routine chest x-ray examination.

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Laboratory studies revealed that the hemoglobin was 14.5 Gm. and the white cell count 8,100. Two concentrated specimens of gastric juice were negative for tubercle bacilli and pathogenic fungi. Guinea pig inoculation and culture for micrococcus tuberculosis were performed and reported to be negative.

Clinical Course.—The patient continued to be asymptomatic. Bronchoscopy was negative. Fluoroscopic examination revealed that the lesion moved with movement of the lung. Biopsy of one of the skin lesions revealed chronic inflammation. On June 14, 1951, the pleura was opened through the bed of the sixth rib. Within the visceral pleura covering the apical segment of the lower lobe and relatively adherent to the mediastinal pleura was an oval, firm, dense mass, which measured 6 cm. by 4 cm. The tumor was peeled away from the periphery of the lung by sharp and blunt dissection. A small air leak was closed and a flap of parietal pleura was raised and sutured to the raw edges of the lung. A catheter was placed in the eighth intercostal space in the midaxillary line.

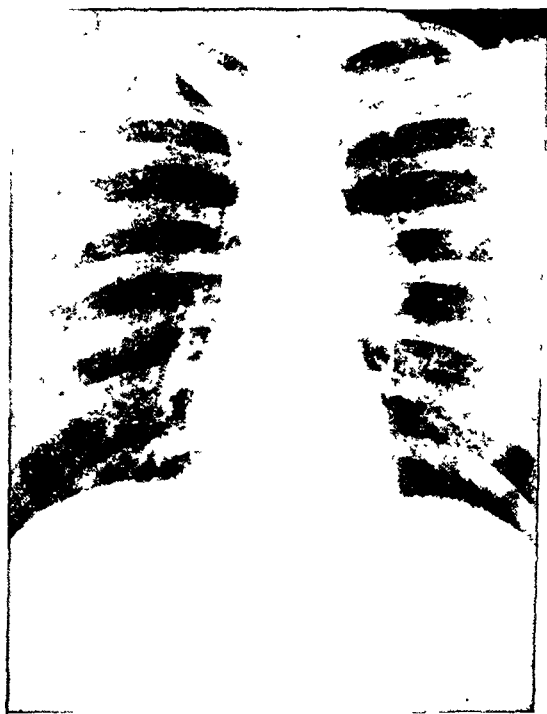


Fig. 1.—X-ray film of the chest, taken May 31, 1951, showing the left hilar mass.

The patient made an uneventful convalescence and was discharged on June 27, 1951. He was completely asymptomatic and in good health when seen on Oct. 27, 1952. At that time x-ray studies were within normal limits.

Pathology Report.—The specimen consisted of a coarsely lobulated, oval, firm mass, completely encapsulated by a thin, fibrous capsule to which a few heavier fibrous strands were attached (Fig. 2). It measured 6 cm. by 3½ cm. by 3 cm. It had a rather solid consistency. Small, yellow flecks were present beneath the capsule. The cut surface was mottled gray-white, yellow, and tan and presented a finely cobbled or naplike texture due to many tiny light gray and pink papillary projections measuring 1 to 3 mm. in diameter. Some of the larger structures had a more translucent appearance. Scattered throughout were many 1 to 2 mm., bright yellow, irregular areas and a few 1 mm. cystic spaces filled with clear fluid or gelatinous material. Thin, fibrous trabeculae crisscrossed the entire surface (Fig. 3).



Fig 2 —Lobulated, encapsulated, gross specimen removed June 14, 1951

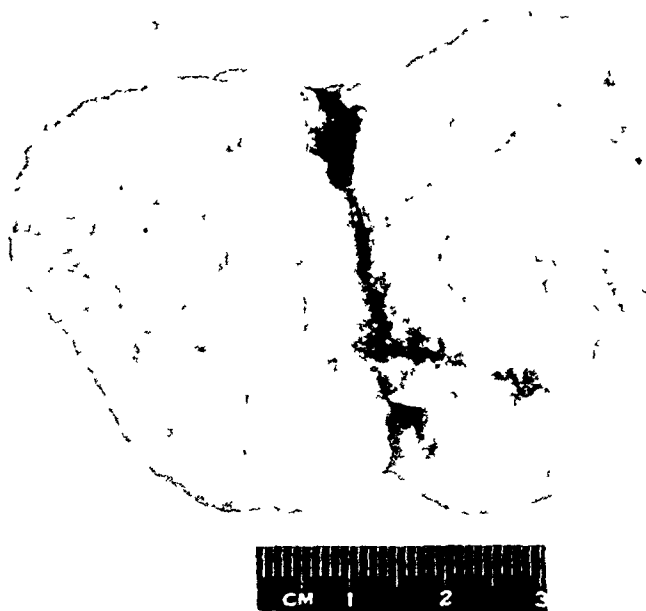


Fig 3 —Papillated cut surface of the tumor

Fig. 4.

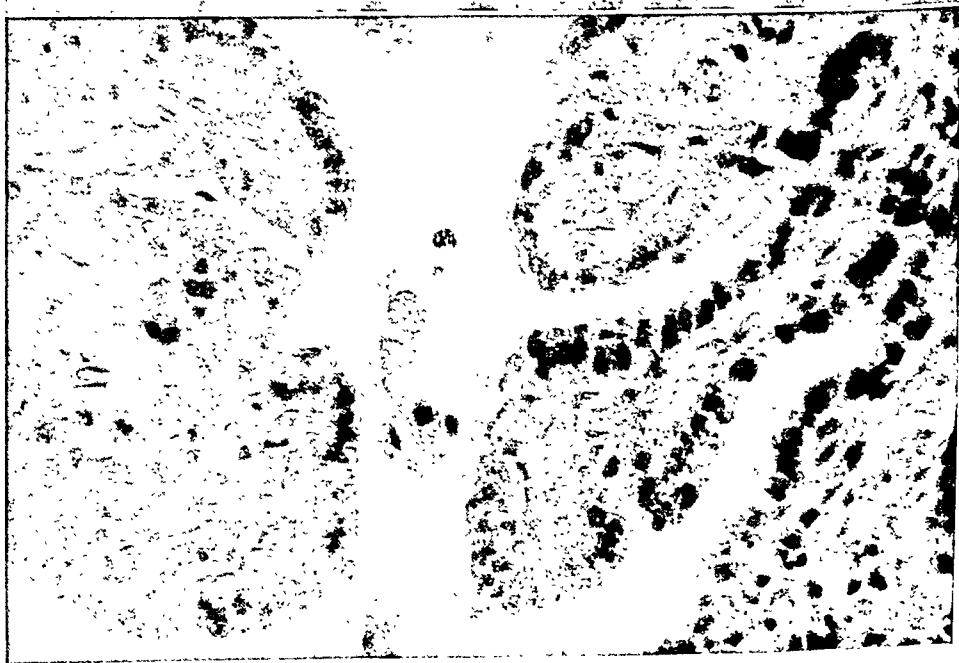
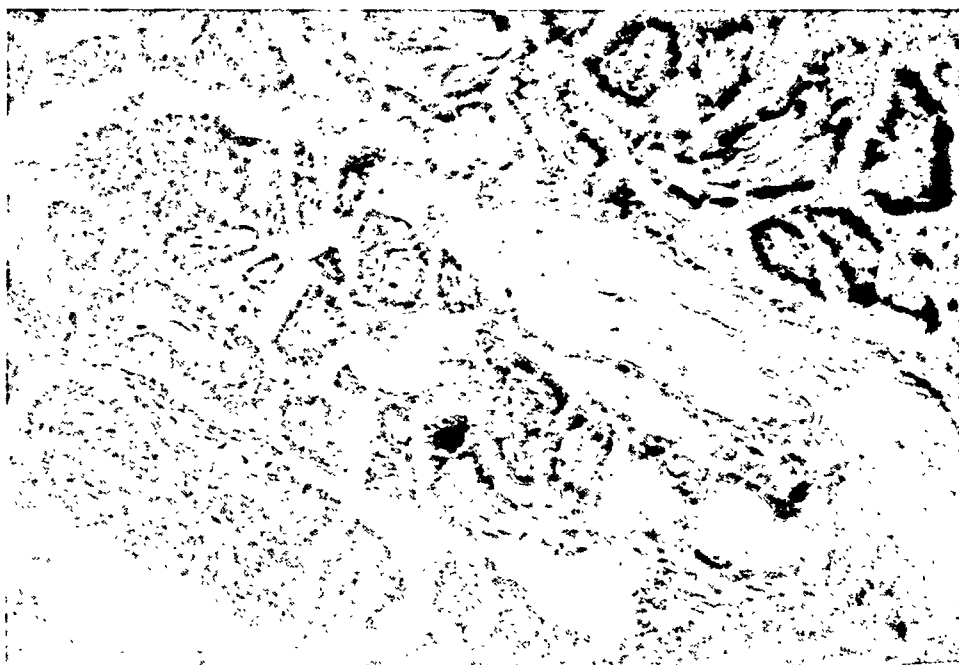


Fig. 5.

Fig. 4.—Low-power microscopic section of the tumor, showing connective tissue papillae covered by cuboidal cells.

Fig. 5.—High-power microscopic section of the tumor, showing epithelial-like mesothelial cells covering stalks. There is no basement membrane.

Microscopically the lesion appeared to be benign, consisting of well-differentiated cells growing in papillary arrangement and enclosed in a fibrous capsule containing a few lymphocytes. The papillary projections were composed of a loose fibrous tissue core, varying considerably in size and covered by uniform cuboidal cells strongly resembling mesothelial cells (Figs. 4 and 5). In some areas, the tissue was rather markedly edematous; in other areas, there were small foci of necrosis and fibrosis accompanied by macrophages with foamy cytoplasm. Basement membranes and mucicarmine positive material were absent.

DISCUSSION

Although this lesion was localized and well circumscribed, it differed from all previously described localized mesotheliomas in that the latter have all been of a fibrous nature. This tumor was essentially epithelial in nature, a characteristic of the diffuse, malignant mesotheliomas.¹ Because of this discrepancy, consideration had to be given to several diagnostic possibilities. Metastatic papillary adenocarcinoma, particularly of the thyroid gland, was considered, but this seemed unlikely because of the pattern of the tumor, its location near the junction of the visceral and mediastinal pleura posteriorly, the morphologic resemblance of the principal cells to mesothelial cells, and the absence of mucicarmine positive material and of a basement membrane. The fact that the patient has remained well for one year and a half fortifies this opinion. Bronchiectatic reactive disease was considered but this was discarded because of the size and discreteness of the mass and its distance from the pulmonary parenchyma. Because of the tenuous connection of the lesion with a minute bronchus, the possibility of fetal lung was entertained, but this diagnosis seemed untenable because of the histologic pattern and the almost complete segregation of the mass from the lung.

The most tenable diagnosis seemed to be localized mesothelioma of epithelial type. This opinion was corroborated by the staff and consultants of the Armed Forces Institute of Pathology.

Many localized pleural mesotheliomas have been treated successfully by conservative resection,³ although Hochberg² states that radical pneumonectomy and pleurectomy should always be employed. Because of the localized, discrete nature of this lesion at operation and because of its location, a simple enucleation was performed. The patient's uneventful course since operation and the apparently benign nature of the lesion tend to justify the procedure employed.

SUMMARY

The successful removal of an unusual localized mesothelioma of epithelial type, occurring at the junction of the visceral and mediastinal pleura, has been described.

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Announcement

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The 34th annual meeting of the American Association for Thoracic Surgery will be held May 3, 4, and 5, 1954, in Montreal, Que., Canada. Headquarters will be at the Sheraton-Mount Royal Hotel.

Requests for Hotel Reservations

These should be mailed *directly* to the Reservation Manager, Sheraton-Mount Royal Hotel, Montreal, Que., Canada. Please mention this Association, type of accommodation desired, date, and approximate hour of arrival. If accommodations are desired elsewhere, please communicate directly with hotel of your choice.

Thoracic Surgical Forum

After due consideration, the Council has decided to try an experiment by assigning one morning session to a "Thoracic Surgical Forum" for the presentation of short papers on current thoracic research, anatomy, modified surgical techniques, etc. Papers at this session will be limited sharply to ten minutes (including the showing of lantern slides or other illustrative material) with three minutes as the maximum discussion of each paper.

These papers will be published together in one issue of THE JOURNAL OF THORACIC SURGERY. Maximum length: 3,000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts for Papers

Abstracts for the presentation of papers at the 1954 meeting, including papers before the Forum, must be received on or before January 1, 1954, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Forum" or "For Regular Program."

Five, repeat five, copies of each abstract should be sent to the Secretary of the Association, Dr. Paul C. Samson, 2938 McClure St., Oakland 9, Calif. They should not be sent to the Editor.

The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Jan. 1, 1954, to be considered for action in Montreal. Applications received beyond this deadline will be deferred for consideration until 1955.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the sponsoring statement on the application form, the sponsors *must* submit a separate letter concerning the applicant direct to Dr. Lyman H. Brewer, III, Chairman of the Membership Committee, 2010 Wilshire Blvd., Los Angeles, Calif. Completed application forms should likewise be sent to Dr. Brewer. These regulations are at the direction of the Council and were made effective in 1952 at Dallas.

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Original Communications

BRONCHIOLAR ("ALVEOLAR CELL") CARCINOMA OF THE LUNG

CAPTAIN CLIFFORD F. STOREY, COMMANDER KENNETH P. KNUDTSON (BY
INVITATION), MEDICAL CORPS, UNITED STATES NAVY, AND BENJAMIN J.

LAWRENCE, M.D. (BY INVITATION)

ST. ALBANS, N. Y.

INTRODUCTION

BRONCHIOLAR or alveolar cell carcinomas constitute perhaps the least common,¹⁻⁶ the most interesting, and the most controversial group of primary pulmonary neoplasms. It has been held by a majority of observers that these tumors are of multicentric origin,⁷⁻¹¹ that they arise from the alveolar lining cells,^{7, 10-12} that they are extremely rare, and that the prognosis of patients with this disease is unequivocally dismal.^{2, 12, 14-17} If, indeed, these tumors invariably arise from multiple primary sites, no mode of treatment can be expected to be permanently beneficial and patients with this form of lung cancer must be judged as therapeutically hopeless.

Our interest in these lesions was stimulated when we encountered, within a relatively short period of time, three patients with small peripheral pulmonary nodules with essentially identical roentgen characteristics (Figs. 1, 2, and 3). Surgical treatment was promptly instituted in two of these cases, the lesion being removed by segmental resection in one patient and by excisional biopsy followed immediately by lobectomy in the other. Both of these patients are alive and well, one of them eighteen months and the other three and one-half years postoperatively. The third patient, whose lesion was demonstrated by serial chest roentgenograms to have remained stable for at least sixteen months, was subjected to an intensive diagnostic work-up, including multiple cultures of the sputum and gastric washings for acid-fast bacilli. While awaiting reports of the cultures, a spread was observed, first

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The opinions or assertions expressed herein are those of the authors and are not to be construed as official or reflecting the view of the Navy Department or the naval service at large.

Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 30, 1953.

in the vicinity of the original lesion, but widespread dissemination soon occurred and all lobes of both lungs became involved with multiple, small, poorly circumscribed nodules (Fig. 4). A pericardial effusion developed and the bloody fluid obtained on pericardiocentesis contained malignant cells

Fig 1.

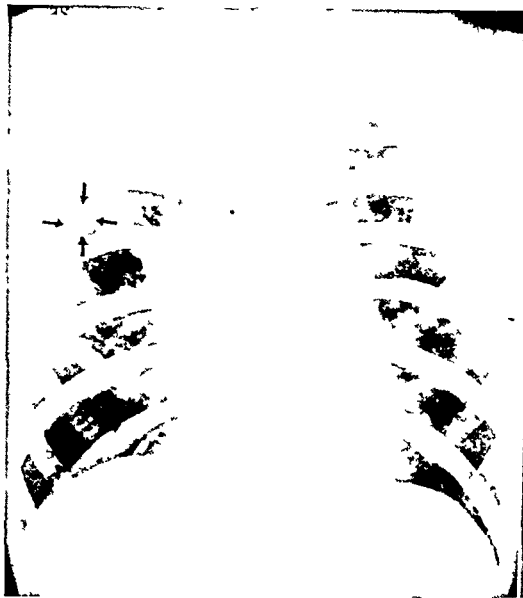


Fig 2



Fig 3

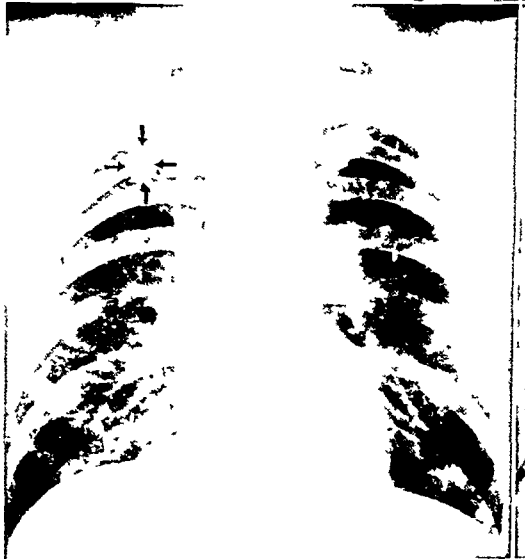


Fig 4



Figs 1, 2, and 3—Chest roentgenograms of three patients, each showing a small, circumscribed, peripheral, pulmonary nodule. Each patient has a bronchiolar carcinoma.

Fig. 4—Chest x-ray view of the same patient shown in Fig 1 made four months later. All lobes of both lungs are now involved by multiple, small, poorly circumscribed nodules. Bronchiolar carcinoma diagnosed by lung biopsy and verified at autopsy.

The diagnosis of bronchiolar carcinoma was established by lung biopsy. The patient died soon thereafter and complete post-mortem examination confirmed the diagnosis. There were widespread local and distant metastases.

The similarity of these three cases was striking and it seemed highly likely that metastases in the third case had taken place from a solitary primary lesion. The literature on this subject was reviewed and it failed to yield convincing evidence to support a number of commonly held opinions pertaining to these tumors. Particularly and most importantly, it has not been clearly shown that this neoplasm is of multicentric origin: on the contrary, there is a substantial array of data that would indicate that these carcinomas arise from a single primary lesion from which they spread to other sites as do most malignant tumors.^{14, 15-22} In an attempt to clarify some of the moot points concerning this disorder, which has been termed "the mystery disease,"²³ a study of all available material concerning bronchiolar carcinoma was undertaken.

MATERIALS

The pathologic material at the Armed Forces Institute of Pathology, comprising a group of 39 clear-cut examples of bronchiolar carcinoma, was studied. Nine cases from the Institute have been previously reported by Swan²² and one by Freedman.²² Those cases are excluded from this report. Four personal cases and four collected from other sources have been added. Thus there has been provided a group of 37 hitherto unreported cases of this entity for review. Reports of 120 patients with this tumor have appeared in the literature since the publication of Swan's paper in 1949. He covered the literature through 1947. Swan²² reported 9 cases and collected 27 which were not included in the review published by Neuburger and Geever²² in 1942. The latter authors had reviewed the literature up to 1942 and had collected 25 cases which they felt represented unmistakable gross and microscopic evidence of "alveolar cell tumor."

One hundred eight of the cases which we have collected from the literature have been abstracted and analyzed. Three cases reported by Drymalski, Thompson, and Sweany²³ and one reported by Graham and Delarue²⁴ were inadvertently misplaced and overlooked when the statistics were compiled and the graphs constructed. Three cases reported by Tillett and Hirsch²⁴ did not come to our attention until after the statistical studies had been completed. Five cases reported by Fisher and Holley²⁵ did not appear in the literature until after the graphs had been drawn. These twelve cases are therefore not included in the statistical studies. The 37 cases reported here have been added to the 108 collected cases to provide a group of 145 patients for statistical study. Where their data permitted, the 24 cases reviewed by Neuburger and Geever,²² the 27 collected by Swan,²² and the 9 reported by him have been added to our material to make a total of 205 cases available for statistical analyses. One of the cases collected by Neuburger and Geever, that of Fried, has been excluded because its authenticity has been

denied. To our knowledge, this includes essentially all unquestioned cases of this disease which have appeared in the literature from the first case report by Malassez²⁴ in 1876 to the present time.

NOMENCLATURE

In searching the literature for accounts of these tumors, one is impressed by the diversity of opinion regarding the benignancy or malignancy of the condition and its site of origin as well as by the conflicting claims of the proponents of sundry theories of etiology. No doubt this confusion has led different authors to select a variety of names by which to designate these neoplasms. Liebow⁵ has compiled a list of thirty-six names by which these tumors have been called, and a considerable number which he did not include have been found in the literature. The sheer multiplicity of this nomenclature appears to reflect the lack of knowledge of the histogenesis of what appears almost certainly to be a single group of tumors. The term "bronchiolar carcinoma" has been adopted for the following reasons: 1. Carcinomas must, by definition, arise from epithelium; 2. an epithelial lining of the pulmonary alveoli has not been proved. On the contrary, there is a considerable weight of opinion, with which we concur, that the alveoli are not lined by epithelial but by mesenchymal cells; 3. bronchioles, on the other hand, are definitely lined by epithelium and therefore, from the histologic standpoint, certainly *could* serve as the site of origin of these tumors; 4. our own histologic studies, as well as those of numerous others, led us to conclude that the bronchioles are, in fact, their starting point.

The importance of the controversy which has raged as to the alveolar versus the bronchiolar origin of this group of neoplasms has been lessened, if not completely obviated, by the observations of Oppenheimer,²⁵ who feels that the doctrine of absolute specificity of the germ layers must be abandoned. She quotes Brachet²⁶ as stating, "In reality the germ layers like the blastomeres have an actual potentiality and a total potentiality; the former is what they normally become, the latter is what they are capable of forming, in addition, under diverse natural or experimental influences." Liebow⁵ has pointed out that the distinction between the alveoli and the bronchioles as the site of origin may be somewhat fatuous as shown by Waddell's²⁷ observations which suggest that the epithelium lining the bronchioles may itself be of mesodermal origin. The important fact from the clinical standpoint is that these lesions arise *peripherally*. Whether from the alveoli or the bronchioles is largely a matter of academic interest.

There is strong evidence that the term pulmonary adenomatosis, implying as it does a benign lesion, is likely to be misleading and we feel that its use should be abandoned. Those who continue to employ that terminology acknowledge that metastases are seen in a significant percentage of cases,²⁸⁻³⁰ even in those patients whose tumors appear histologically benign. Furthermore, not infrequently histologically benign and malignant areas are found in different portions of the same specimen, as in the cases reported by Dacie and Hoyle,³ Wood and Pierson,³¹ Laipply and Fisher,³² and others.^{16, 30, 33}

Serial sections in such cases have shown imperceptible merging of one into the other in some instances, and abrupt changes from benign to malignant in others. Whatever the diagnostic title selected, it would appear most desirable that common agreement be reached on an acceptable name for this group of tumors. Such an agreement would facilitate statistical reporting and would make more readily accessible reports in the literature pertaining to these lesions. Liebow⁵ has adopted the term bronchiolar carcinoma and this nomenclature is also favored by Stewart.⁴⁴

Swan¹³ prefers that the term "pulmonary adenomatosis" be reserved for tumors which fulfill the following criteria: (1) alveolar-cell proliferation, characterized by the appearance of tall mucus-producing cells; (2) absence of an intrinsic tumor of the bronchial tree; and (3) absence of primary adenocarcinoma of any other part of the body. For those tumors which metastasize in addition, he coined the term "cancerous adenomatosis." Obviously this classification did nothing to lessen the confusion which already existed. Furthermore, Swan's diagnostic criteria would appear to be in need of revision. It is interesting to note, as a matter of fact, that in three of the cases reported by Swan¹³ the criteria which he himself proposed were not fulfilled. Those three patients were not autopsied and one cannot be certain, therefore, that they did not have adenocarcinoma elsewhere in the body.

At the time when the diagnosis of this neoplasm was made almost exclusively at autopsy, the criteria proposed by Swan may have been practicable. Today, however, the diagnosis is often made by cytologic examination of the sputum or histologic study of the resected specimen. In addition the fact that these tumors are formed by *alveolar-cell* proliferation is far from proved. There is strong evidence to indicate, on the contrary, that the lesions have their inception in the basal cells of the terminal bronchioles. Although usually composed of tall columnar cells, they may be low columnar, or even cuboidal in type. Finally, mucus production is not an essential feature of this neoplasm. Many unequivocal examples of this tumor have produced little or no mucus. The following diagnostic criteria would appear more applicable to the lesions under discussion: (1) a tumor characterized by alveoli lined by epithelial cells of columnar or cuboidal type with eosinophilic cytoplasm and basally placed nuclei; (2) preservation of the pulmonary architecture; (3) absence of an intrinsic tumor of a bronchus; and (4) absence of *evidence* of primary adenocarcinoma in any other part of the body.

HISTOGENESIS

Passler, according to Fried,³⁵ was the first to give a comprehensive discussion of the origin of the cancer cells in bronchiolar carcinoma. In 1896 he reviewed 54 cases of lung cancer, of which he concluded 47 originated in the bronchial mucosa, while in the others the histogenesis could not be established. In 1912 Alder³⁶ published his monograph in which he reviewed 374 cases of carcinoma of the lung. He stated, "It is now held that carcinoma starting from the pulmonary alveoli is exceedingly rare, and some go as far as to deny its existence altogether."

Bell,³⁷ Ham and Baldwin,³⁸ Ikeda,¹¹ Sims,³³ Macklin,³⁹ and others believe that the epithelium in the fetus undergoes desquamation before the sixth month but that an occasional cell is left attached to the septal wall, proliferating in times of stress or strain on the alveolar epithelium. These authors were of the opinion that these septal cells, epithelial in nature, give rise to alveolar-cell tumors. The evidence in favor of an epithelial lining of the pulmonary alveoli has been ably summarized by Delarue and Graham,⁴⁰ who concluded that such a lining does exist and that "alveolar-cell carcinoma" probably takes its origin there. Herbut,¹⁸ Smith and Gault,⁴¹ Simon,⁴² Sweany,⁴³ Bliss,⁴⁴ and Casilli and White⁴⁵ do not accept the alveolar origin of these tumors but rather believe them to arise from the lining of the terminal bronchioles. They base their opinion on the following premises: 1. There is no epithelial lining of the alveoli. 2. These tumors can be seen extending from bronchioles to alveoli, and 3. Histologically, the cells resemble the lining cells of the normal bronchiole.

Herbut¹⁸ states that primary carcinoma of the lung arises from the basal cells of bronchi or bronchioles and further differentiation or lack of differentiation determines the distribution of these cells in relation to the rest of the pulmonary parenchyma. If the tumor forms cuboidal or columnar cells, they will line the alveolar septa in accordance with their inherent property to line spaces and so will produce the well-known alveolar distribution.

Our studies have shown no evidence of multicentric origin of the tumor within the lung. We believe the overwhelming evidence favors the unicentric origin from the lining of the terminal bronchioles with spread to other portions of the lung by way of the air passages following slough of the tumor cells, as well as by way of the lymphatics and the blood stream. Multiple primary cancers can and do occur, of course, particularly in paired organs.⁴⁶ The burden of proof, however, lies with the one who contends that multiple lesions of an identical histologic type represent primary tumors rather than metastases from a single source of origin. Dr. Evarts Graham⁴⁰ is one of many who is firmly convinced that this tumor is of multicentric origin, and he and Delarue have set forth clearly the evidence on which that conviction is based.

ETIOLOGY

There is a striking morphologic resemblance of bronchiolar carcinoma in man to jaagsiekte, an infectious disease in sheep. Jaagsiekte, a South African word derived from the Dutch, is the name given pulmonary adenomatosis when seen in sheep. The name means "driving sickness," and the symptoms appear in sheep when they are driven some distance. A virus etiology is strongly suspected since the disease is easily transmitted by housing infected sheep together with healthy sheep. Experimental transmission of the disease has been generally unsuccessful. Shepherds do not acquire the disease; however, several possible exceptions have been recorded. Histologically, the

lesions seen in jaagsiekte are composed of alveoli lined by a regular layer of nonciliated, high cuboidal epithelium, often papillary in nature, with prominent interstitial fibrosis. The stroma is seldom invaded. Aynaud and his associates⁴⁶ reported a case of jaagsiekte in sheep in which metastasis to mediastinal and hilar nodes occurred. These findings were later confirmed by Dungal and his co-workers.⁴⁷ There is no evidence to indicate that bronchiolar carcinoma in man is an infectious disease. Efforts to transmit the disease from man to laboratory animals have been unsuccessful. No causal relationship between the infectious disease in sheep and the malignant process in man has been shown, although a few reported cases of human bronchiolar carcinoma have been exposed to sheep ill with a pulmonary disorder.

Campbell⁴⁸ observed primary pulmonary tumors in mice when they were exposed to dust and tars of various kinds. He believed the tumors originated from alveolar cells which were originally benign and became malignant following continued irritation. The carcinogenic effects of urethane, dibenzanthracene, and other carcinogens in laboratory animals have been generally accepted. When these carcinogens are given subcutaneously, intraperitoneally, or intratracheally in susceptible mice, 100 per cent develop multiple lung tumors within four months. The histologic structure of these induced tumors is similar to the bronchiolar carcinoma seen in man. Metastasis to hilar nodes has been described. Review of the reported cases and those in this series fail to suggest a close etiologic relationship between any of the common irritants and bronchiolar carcinoma. The necessity for caution in the application of results obtained in laboratory animals to disease processes in human beings is well recognized.

PATHOLOGY

Gross.—(Fig. 5.) Bronchiolar carcinoma consistently begins in the peripheral portion of the lung. The tumor frequently presents as discrete nodules varying in size from several millimeters to ten centimeters in diameter. The nodules are usually irregular in outline with sharp borders demarcating them from the adjacent lung tissue. In some instances there is a coalescence of the nodular masses, giving a striking resemblance to the stage of gray hepatization of lobar pneumonia. On cut section, the surface varies from gray-tan to yellow-brown and is moderately firm in texture. Mucus often exudes from the sectioned tumor. Cavities within the tumor are rarely noted. Large gross areas of atelectasis are seldom seen but irregular focal areas of atelectasis adjacent to the tumor are frequently present.

A constant gross finding is the absence of primary involvement of the major bronchi. In rare instances where the tumor had grown to large size late in the course of the disease, the bronchi may be secondarily invaded by the surrounding tumor. Frequently, the nodules extend to the pleura where they appear as slightly raised, umbilicated masses. Pleural effusion is fairly common and is often serosanguineous in character.

Microscopic.—(Figs. 6 to 15.) The histologic structure of bronchiolar carcinoma is characteristic and distinct. The tumor is composed of alveoli lined

by cells which are usually tall but they may be of the low columnar or even cuboidal type. The cytoplasm is eosinophilic. The nuclei are located basally and are round or ovoid in shape. The cells are almost always nonciliated and are attached at their base to the unaltered alveolar wall. In at least three reported instances the lining cells have been ciliated. The architectural pattern of the lung is seldom interrupted, the tumor cells appearing to outline the lumina of the alveoli and terminal bronchioles. In general, the growth pattern is remarkable for its uniformity. Characteristically the tumor



Fig 5—Gross specimen of a lung showing the typical appearance of bronchiolar carcinoma. Multiple small subpleural nodules are well shown.

is made up of well-differentiated cells without anaplasia, but lesions with more malignant features are encountered and the histologic picture may vary in different portions of the same tumor. Mitotic figures are rare in the typical case. The tumor cells show papillary formation within the alveoli and frequently desquamate into the alveoli. Mucicarmine stains usually, but not invariably, reveal mucin present within the cytoplasm of the tumor cells as well as in the extracellular spaces. Vacuoles of variable size in the cytoplasm are proved to contain fat when differentially stained with Sudan III.

Fig. 6

Fig. 7

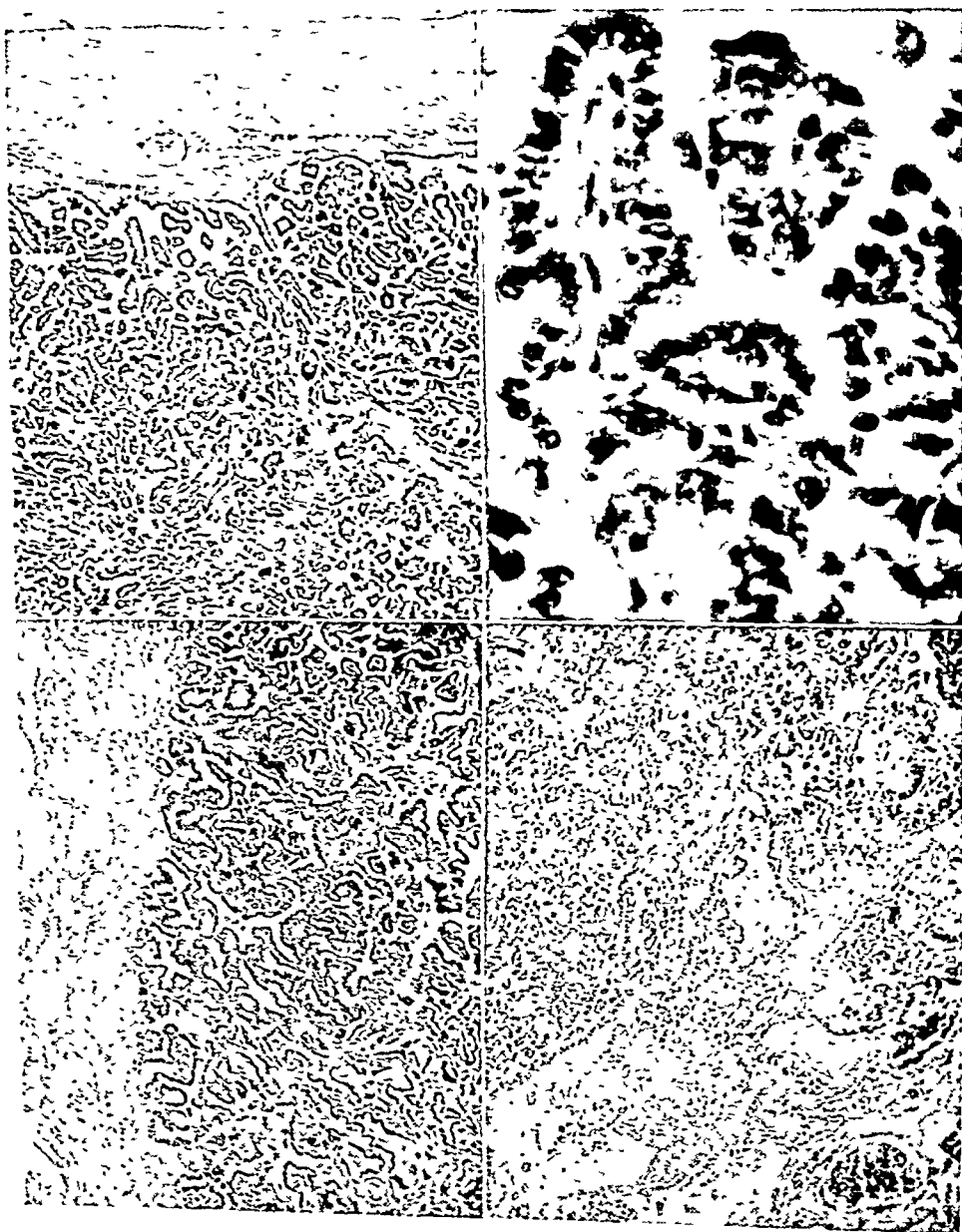


Fig. 8

Fig. 9.

- Fig. 6—Typical low-power view of bronchiolar carcinoma ($\times 71$).
 Fig. 7—High-power view showing alveoli lined by columnar neoplastic cells with a tendency to papillary formation ($\times 594$).
 Fig. 8—Jaagsiekte in lung of sheep ($\times 71$).
 Fig. 9—Bronchiolar carcinoma showing desquamation of tumor cells in alveolar spaces ($\times 71$).

Fig 10

Fig 11.

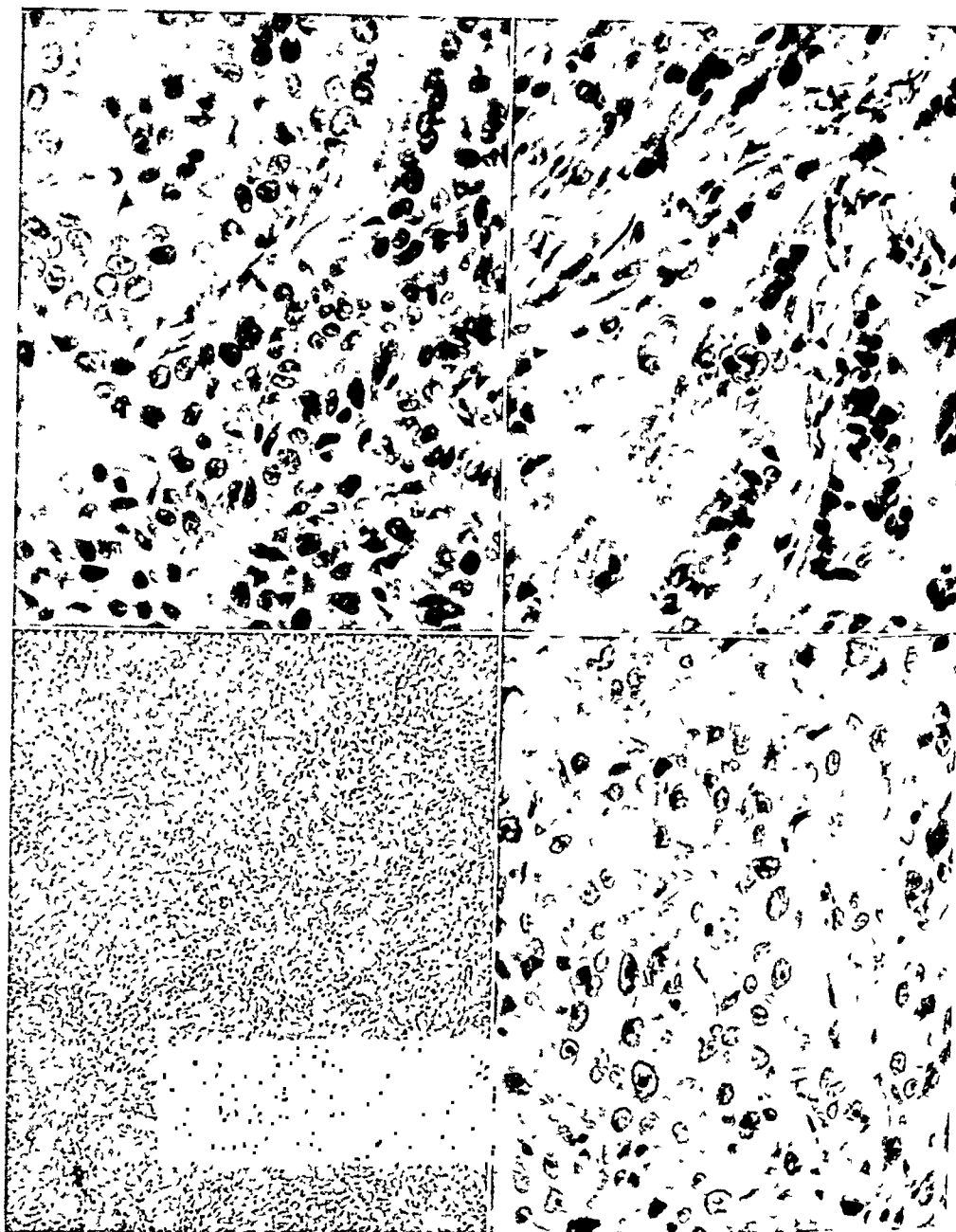


Fig 12

Fig 13

Fig 10—High-power view showing desquamated tumor cells (X570)

Fig 11—Section showing area of anaplasia with occasional signet ring cells (X570).

Fig 12—Focal area of metastasis in liver from bronchiolar carcinoma (X80)

Fig 13.—Giant- and spindle-cell variant of bronchiolar carcinoma (X570).

The stroma of the pulmonary septa may be normal or contain an increased number of thick collagen fibers. Elastic fibers are inconspicuous. Foci of inflammatory cells, the majority of which are polymorphonuclear neutrophils, are most commonly associated with foci of necrosis. Anthracotic pigment is occasionally phagocytized by the tumor cells. Psammoma bodies are infrequently found in sections of the tumor and, when present, are usually surrounded by tumor cells.

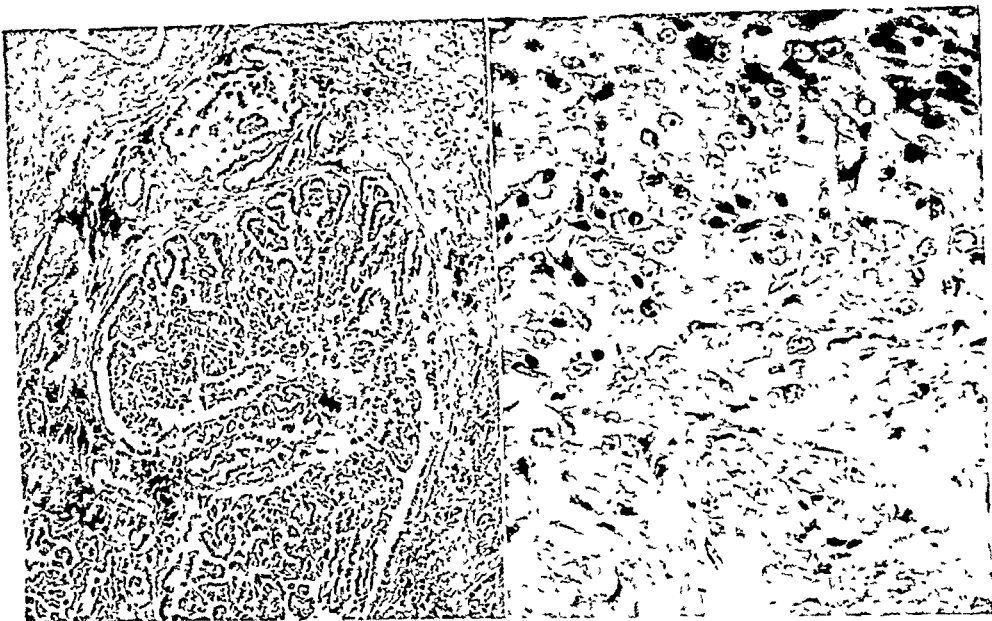


Fig. 14.

Fig. 15.

Fig. 14.—Bronchiolar carcinoma in which desmoplasia (upper left) is a prominent feature ($\times 76$).

Fig. 15.—High-power view of desmoplastic reaction adjacent to the tumor ($\times 570$).

Lymphatic invasion of the lung is demonstrable in sections from over 50 per cent of the cases. Small nests of tumor cells are conspicuous in the perivascular lymphatics. Clusters of tumor cells are frequently found lying free in the alveolar spaces in the tumor-bearing area as well as in distant portions of the bronchial tree. Intrapulmonic spread would be expected to occur when malignant cells are inspired into the air spaces and there set up new growths on the alveolar septa.

The review of cases in this series which had been diagnosed as pulmonary adenomatosis showed no significant changes in gross and microscopic findings from that seen in bronchiolar carcinoma. Examination of the hilar and mediastinal lymph nodes in cases of so-called pulmonary adenomatosis revealed the presence of metastatic tumor. In view of the evidence that this tumor does metastasize locally within the lung and to lymph nodes and other organs, the use of the term "pulmonary adenomatosis" no longer seems tenable, and the tumor should be classified as bronchiolar carcinoma.

CLINICAL FEATURES

Incidence.—It has been variously estimated that this tumor constitutes between $1\frac{1}{2}$ and 5 per cent of all pulmonary carcinomas. It appears that the latter figure is more nearly correct.^{10, 17, 30} In our experience the incidence has approximated 5 per cent. There is conclusive evidence to indicate that these tumors are frequently reported as peripheral adenocarcinoma, and it appears almost certain that this tumor is not as rare as it is reputed to be.

Racial Incidence.—A vast majority of the reported cases have occurred in the Caucasian race (Fig. 16). Among 205 patients, the race was given for 116, of whom 111 (95.7 per cent) were white. In view of the fact that a large percentage of the reported cases have been from this country, where Caucasians constitute approximately 90 per cent of the population, it appears that these tumors exhibit no racial predilection.

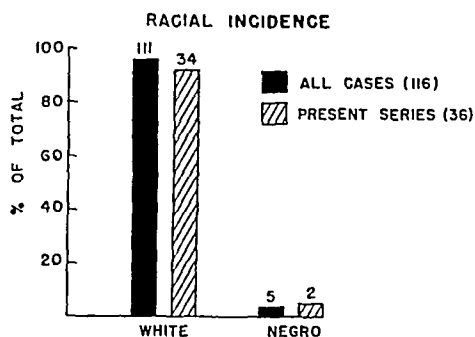


Fig. 16.

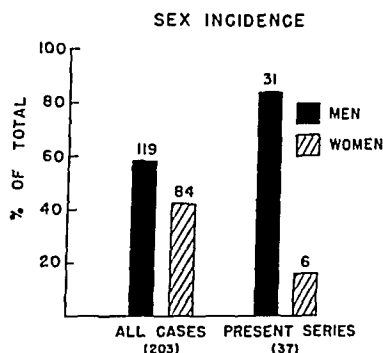


Fig. 17.

Figs. 16 and 17.—The number of patients on which these and the succeeding graph are based will vary from graph to graph. This is necessitated by the fact that reports of cases collected from the literature varied in their completeness and all of the desired data were not available on each of the cases.

Sex Incidence.—Many authors have observed that bronchiolar carcinoma occurs with approximate equal frequency in women and men.^{2, 8, 11, 17, 30, 49} Among the 205 cases analyzed, the tumors were in men in 119 instances (58 per cent), in women 84 times (41 per cent); the sex was not indicated in the two case reports (1 per cent) (Fig. 17). These figures are in sharp contrast to those applicable to bronchiogenic carcinoma, where a strong predominance in male patients has been clearly established. Various reports have indicated that the ratio of male to female among patients with bronchial carcinoma is at least 5 to 1 and may be as high as 10 to 1. It is generally believed that at least 80 per cent of the cases of the common forms of lung cancer occur in men. If one were to exclude the 37 cases reported herein from those collected from the literature, the residual group of 166 patients would consist of 88 men and 78 women, an almost equal sex distribution. The 37 new cases included in the present report represent chiefly military personnel or veterans, thus comprising a selected group consisting principally of men. These figures firmly substantiate the belief that there is no real sex predominance in bronchiolar carcinoma.

Age Incidence.—The youngest patient reported with bronchiolar carcinoma was a boy of 16 and the oldest, a man of 89 years. The average age was 54 years and the median age also 54 years. Fifty-four per cent of the patients were between the ages of 40 and 60 years, and 85 per cent fell in the age group of 30 to 70 years (Fig. 18). These patients were therefore predominately in the so-called "cancer age" and the age incidence of this neoplasm does not differ materially from that of bronchial carcinoma.

Fig. 18.

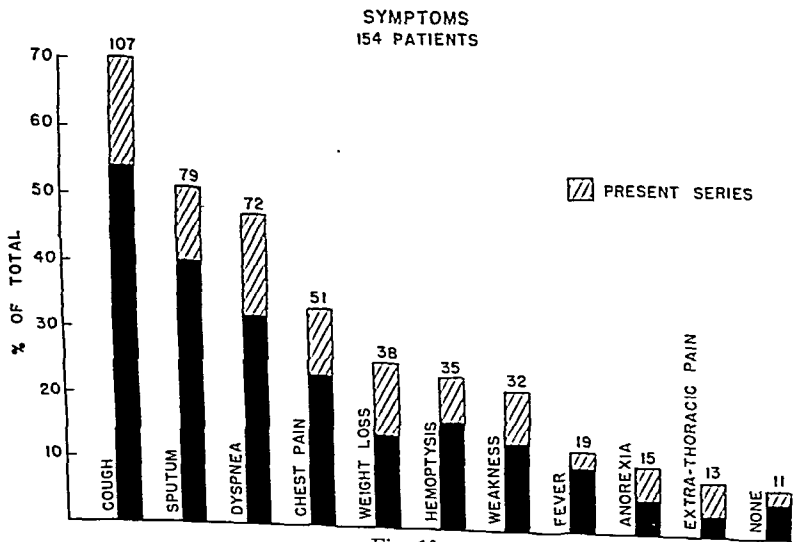
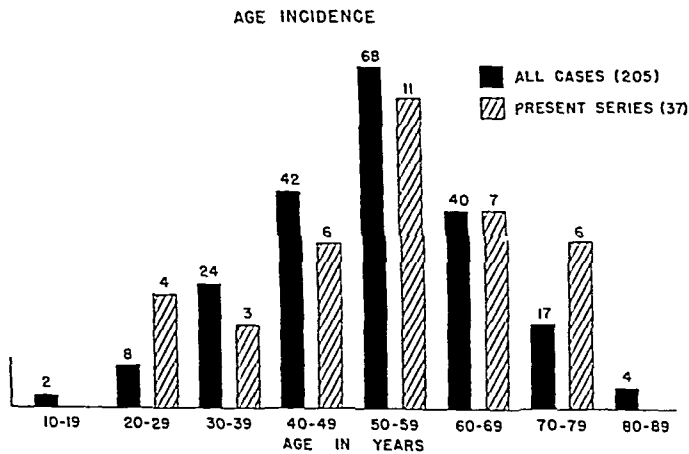


Fig. 19.

Fig. 19.—On this and several succeeding graphs the cases in the present series have been added to the collected cases and are graphically represented as percentage of the total.

Symptoms.—The presenting symptoms are shown in Fig. 19. In view of the fact that the patient's symptoms were frequently described incompletely,

if at all, in the original case reports collected from the literature, the figures on this graph must be interpreted as representing relative rather than absolute values. For example, cough, which is without question the most frequent symptom in patients with this tumor, was specifically mentioned in only 107 (70 per cent) of 154 patients. The percentage values in our group of 37 patients reflect more accurately the true incidence of the various symptoms. These data were obtained from the patient's original clinical records. The most common symptoms, in approximate order of frequency, are cough, sputum, dyspnea, chest pain, weight loss, hemoptysis, weakness, fever, anorexia, and pain other than in the chest.

It is noteworthy that 11 patients (7 per cent of 154 cases) had no symptoms. In these individuals the lesion was accidentally discovered on routine chest roentgenograms, and the diagnosis was made on histologic study of the excised tumor. There is reason to believe that the prognosis is much better in this group of patients than in those who sought medical care because of the presence of symptoms.

The character and degree of the cough in these patients was highly variable. In general it was not of the harassing type and was usually proportionate to the amount of sputum production. In a fairly large percentage of patients the cough was dry; in a majority of this group it was described as mild or slight.

The production of sputum, the second most common symptom, was encountered somewhat less frequently than cough. Numerous patients raised no sputum and the amount and character showed great variation among the patients whose cough was productive.

Dyspnea, a common symptom in the group as a whole, was not usually seen early in the course of the disease. The presence of dyspnea almost invariably indicated an advanced process with widespread pulmonary involvement. The degree of the dyspnea was most often directly proportional to the extent of the tumor, reflecting the degree of diminution of normally functioning lung tissue.

Chest pain, indicative of pleural involvement, was not an uncommon complaint. The pain was usually mild to moderate in character, rarely excruciating, and was definitely related to respiratory movements.

Weight loss, next in frequency, was also a late manifestation. It is, in fact, remarkable how few systemic symptoms these patients present until the disease process is far advanced. In general, weight loss was observed only after cough, expectoration, and dyspnea had become prominent. The majority of patients maintain an excellent nutritional status until they approach the terminal phase.

Hemoptysis is by no means as rare as some authors have considered it to be.^{s, 16, 50, 51} It was rather often the first symptom, although the amount was usually small, often no more than streaking or pink-tinged sputum. Frank hemorrhages of serious degree rarely occur. Weakness, seen only in advanced disease, usually accompanies the onset of dyspnea and weight loss and like those symptoms does not make its appearance until there is massive pulmonary

involvement. Fever, although mentioned in 9 per cent of the cases, is not a characteristic feature. Many of these patients die of a terminal pneumonia and the presence of fever commonly denotes the presence of a suppurative or inflammatory pulmonary complication. Anorexia, a very late symptom, appears only when dyspnea has become marked. A majority of patients retain a satisfactory appetite until just before death. Extrathoracic pain, mentioned in 6 per cent of patients, although occasionally attributable to an unrelated cause, almost always denoted a distant metastasis. Cyanosis occurs only terminally.

A review of these symptoms makes clear their completely nonspecific character. Nothing in the symptomatology is characteristic of bronchiolar carcinoma; the symptoms are rather those of any extensive chronic pulmonary disease. This point is emphasized by the fact that the most common clinical diagnosis in these patients was pulmonary tuberculosis, followed (not necessarily in order of frequency) by such conditions as sarcoidosis, silicosis, bronchopneumonia, metastatic carcinoma, fungus disease, bronchiectasis, Hodgkin's disease, and atypical pneumonia.^{12, 13, 24, 25, 32, 42, 49, 52}

Physical Signs.—There are also no physical signs that are characteristic or even highly suggestive of bronchiolar carcinoma. Those abnormal findings encountered will depend upon the location, character, extent, and distribution of the disease and upon the presence or absence of complications, such as pneumonia. The great variation of the physical findings from case to case makes it virtually impossible to tabulate the abnormal signs seen in patients with this neoplasm. Furthermore, no useful purpose would be served by recounting the findings on physical examination described in the individual case reports.

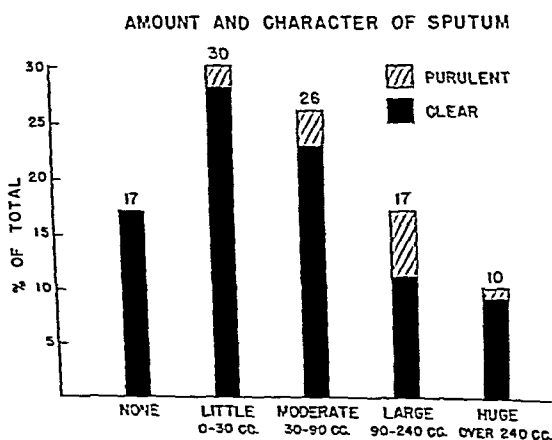


Fig. 20.

Amount and Character of Sputum.—Reference to the sputum was sufficiently precise to permit analysis in 100 patients. The results are shown in Fig. 20.

It has been emphasized repeatedly that this disease is characterized by the production of large amounts of clear, frothy sputum, but this point is scarcely borne out by the available data. Only 27 of 100 patients (27 per cent) raised more than an average of 90 c.c. in twenty-four hours. It is true that a number of patients produced fantastic quantities of sputum. For example, Fox⁵³ mentions a patient whose sputum production amounted to 3 to 4 quarts (2,839 to 3,785 c.c.) daily. Kennamer's⁵¹ patient raised 3,122 c.c. (3.3 L.) in one twelve-hour period and usually brought up 2 to 3 pints per day. Kern, Lewinsky, and Curran⁵⁵ report a patient who, in less than four months, spat up 78.2 L. of expectorate (some 20 gallons of fluid), far exceeding his body weight of 67.1 kilograms. Sputum production reached nearly 2,000 c.c. in some twenty-four hour periods and often exceeded the urine output. The patient reported by Rey and Rubenstein⁵⁶ raised 1,500 c.c. daily, and Wood's⁵⁷ patient produced up to 1 quart (946 c.c.) a day.

It is obvious that, if long continued, a huge daily sputum output will result in serious fluid, electrolyte, and protein depletion. These outstanding examples of severe bronchorrhea are scarcely characteristic, however, of the typical patient with this tumor. Of the patients, 17 per cent had no sputum, and 56 per cent raised less than 90 c.c. daily. Thus the sputum production varied from none to moderate in quantity in 73 of 100 patients. The character of the sputum has been described as clear, watery, glairy, frothy, mucoid, or resembling pale soapsuds. This description of the typical sputum may be accepted as an accurate one, for it was of this type in 71 of 83 patients whose sputum was adequately described. Only 12 of 100 patients (12 per cent) raised mucopurulent or frankly purulent sputum and in a majority of these individuals complications, such as bronchiectasis or bronchopneumonia, were present. Only 1 of 100 patients had excessively large quantities of purulent sputum.

Hemoptysis.—A number of writers on the subject of bronchiolar carcinoma have stated that hemoptysis rarely occurs.^{5, 16, 50, 51} Such is not the case. The patients in whom adequate data concerning the sputum were available have been analyzed as to the presence or absence of hemoptysis and the results are given in Fig. 21.*

It will be noted that blood-spitting occurred on one or more occasions in 35 of 71 patients (49 per cent) in whom hemoptysis was specifically mentioned as to its presence or absence. Since blood was definitely raised by 35 of 100 patients whose sputum was described at all, it occurs in at least 35 per cent of patients with this malignancy. Furthermore, it scarcely can be assumed that none of the 29 patients in whom hemoptysis was not directly mentioned never spat blood during their illness. Hemoptyses were usually small but often occurred repeatedly. This symptom is not necessarily a late one. In a number of reported cases as well as in several patients in this series, hemoptysis was one of the earlier complaints.^{9, 10, 13, 11, 17, 20, 29, 54, 58-62}

Duration of Symptoms.—The prevailing opinion appears to be that bronchiolar carcinoma is a slowly progressive chronic pulmonary new-growth which

*Watson and Smith did not describe the sputum in their patients and those cases are not included in this graph. They mentioned hemoptysis in 9 of their 33 patients, however.

is not a debilitating disease until very late, that it gives rise to remarkably few systemic symptoms, and usually kills by the sheer extent of the pulmonary involvement.^{6, 42, 50, 51, 63} This impression of its chronicity is well substantiated by the reported figures. The clinical data permitted analysis of 151 patients in respect to the duration of symptoms. The results are shown in Fig. 22.

The duration has been calculated from the time of onset of symptoms clearly attributable to the disease to the date of death if the patient died, to the date of operation if resection was carried out and the patient has remained free of symptoms postoperatively, and to the date of the last report of patients with recurrent or persistent symptoms with or without surgery.

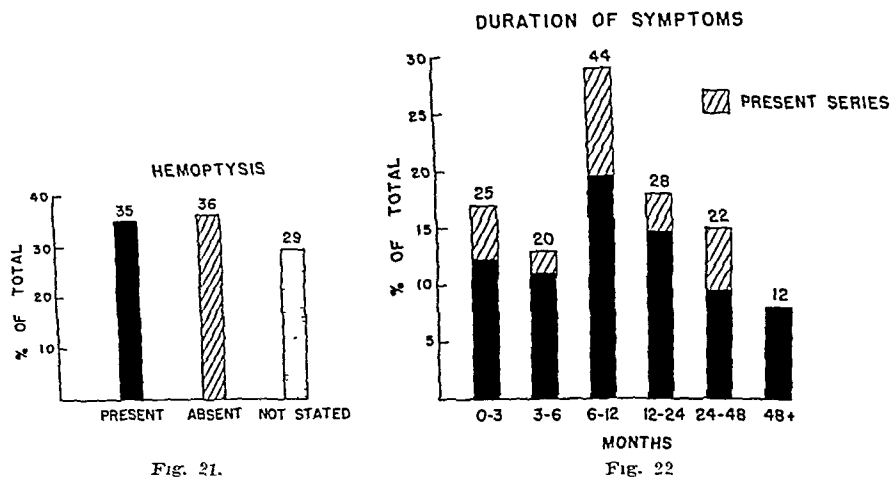


Fig. 21.

Fig. 22

It is entirely possible, that the criteria have been too rigid in evaluation of the patient's symptoms and the average duration of symptoms may be longer than the figures in the above graph would indicate. In a number of reported cases as well as several of our own, symptoms suggestive of a pulmonary disorder were present considerably longer than we have indicated. It has been deemed advisable, however, to date the duration from the time of the appearance of symptoms which without reasonable doubt can be ascribed to the neoplasm. On that basis, symptoms were present less than six months in only 30 per cent of the patients. Their duration exceeded one year in 41 per cent and two years or more in 34 patients or 23 per cent of the group analyzed from this standpoint. The 45 patients whose symptoms were of relatively short duration includes those who never had symptoms as well as many of those who received the benefits of early excisional surgery.

ROENTGENOGRAPHIC FINDINGS

Valentine and Wynn-Williams,²⁹ in summarizing the clinical and radiologic features of three cases which they reported, stated that "the clinical and radiological appearance of these three patients are typical of those hitherto described in that they are unlike, suggestive only in their variability and

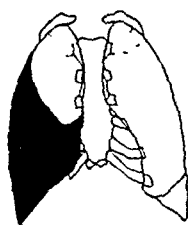
undiagnosed before death." Their statement adequately summarizes our own impression of the roentgenographic findings in patients with bronchiolar carcinoma.

One hundred fifty-three cases, including those reported here, have been collected in which the chest roentgenograms were illustrated, available for review, or in which the x-ray findings were described in sufficient detail to permit their classification. To diagram them all accurately would require an impractical number of drawings. It has been possible, however, to devise twelve diagrammatic figures which depict with reasonable accuracy the radiographic picture presented by these lesions. The diagrams are shown in Fig. 23.

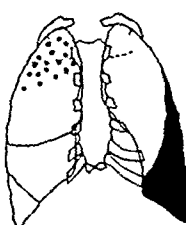
Bilateral nodular lesions, varying in size from a millet seed to a cherry, rounded in contour but with indistinct margins fading imperceptibly into the surrounding lung and involving all lobes of both lungs, often have been said to be characteristic of this variety of lung cancer. Fortunately, this hopeless picture is encountered in but 20 per cent of patients at the time of the first chest x-ray film which demonstrates their lesion. The fact that these tumors are first observed as a solitary peripheral nodule in 26 per cent of the patients provides ample reason for considerable optimism. More than two-thirds of the patients showed unilateral lesions on their first radiographic examination.

In slightly over one-half of the entire group the tumors were apparently confined to one lobe at the time of their discovery. A pleural effusion was present on the occasion of the initial examination in 8 per cent of the patients and this often obscured the primary pulmonary lesion. It must be borne in mind that these illustrations are purely diagrammatic; in actuality, the sharp distinction between the diffuse consolidated type of disease and that presenting as multiple nodules, as depicted, is distinctly uncommon. Far more frequently, areas representing each of these types are simultaneously present and they fade into one another. Sufficient coalescence of multiple nodules gives rise to a homogeneous density. A complicating pneumonia will produce the same picture. Although classic examples of the diffuse and nodular types are occasionally encountered, they are the exception rather than the rule and represent but a stage in the disease process. Separation of the lesions in these patients into the two types seems to be a purely artificial division, dependent almost solely upon factors such as the stage at which the patient is observed and the presence or absence of complications. In this connection it is interesting to note that in the case described by Malassez,²⁴ the first example of this entity to be reported and the prototype of the nodular form of the disease, there was present, in addition to multiple nodules, diffuse consolidated areas. Furthermore, Musser's⁶⁴ case, the first patient with the diffuse form to be reported, presented multiple nodules as well as diffuse consolidation.

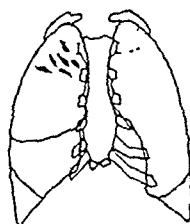
Nodular lesions eventually coalesce in patients who survive sufficiently long to permit this to occur. Serial films frequently demonstrate marked changes in the radiographic picture. It can be concluded, therefore, that



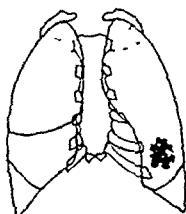
MASSIVE PLEURAL EFFUSION
(5%)



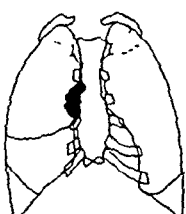
PLEURAL EFFUSION
WITH NODULES IN SAME
OR OPPOSITE LUNG (3%)



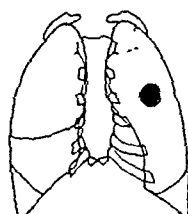
SCATTERED INFILTRATIONS
CONFINED TO ONE LOBE (4%)



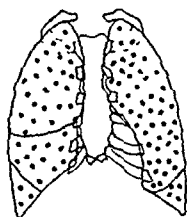
WELL-DEFINED AREA
OF PNEUMONITIS IN A
SINGLE LOBE (8%)



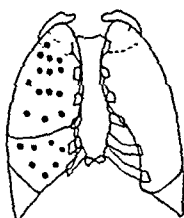
PARAHILAR MASS (3%)



SOLITARY PERIPHERAL
NODULE (21%)



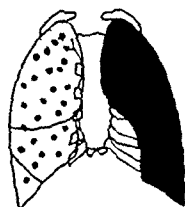
BILATERAL NODULAR LESIONS
ALL LOBES (20%)



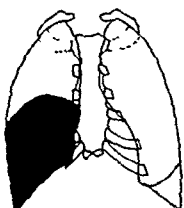
UNILATERAL NODULAR
INFILTRATIONS INVOLVING
ONE OR MORE LOBES (1%)



CONSOLIDATION IN ONE AREA
WITH NODULAR DENSITIES
ELSEWHERE (5%)



CONSOLIDATION OF A LUNG
WITH CONTRALATERAL
NODULES (3%)



CONSOLIDATION OF ALL OR
PART OF A LOBE (16%)



CONSOLIDATION OF ENTIRE
LUNG (1%)

Fig 23—Diagrammatic outline of the lesions seen in the chest roentgenograms of patients with bronchiolar carcinoma at the time of their first radiographic examination

there is no characteristic x-ray appearance of bronchiolar carcinoma. The disorder may mimic almost any variety of pulmonary lesion; a small number of patients have even shown cavitation on x-ray examination. It is an unfortunate fact that those patients exhibiting the most suggestive picture are those with far-advanced bilateral lesions. In this situation the diagnosis is a matter of interest but not of importance, for the prognosis in such patients is utterly hopeless.

METHOD OF DIAGNOSIS

Although this tumor was first described by Malassez²¹ seventy-seven years ago, until fairly recently the diagnosis was made only at post-mortem. The diagnosis of this neoplasm was first made in a living patient in 1936 when Skorpil⁶⁰ did a left upper lobectomy for a lesion which proved to be a bronchiolar carcinoma ("alveolar epithelial carcinoma"). No further cases were diagnosed ante mortem until the resection by Wood and Pierson in February, 1943. They removed the left lower lobe for a pulmonary lesion of uncertain type. Histologic examination showed it to be a bronchiolar carcinoma. Graham⁴⁰ performed lobectomy in June, 1943, for a similar lesion, the third patient with this neoplasm to be treated surgically. Among the cases which we have reviewed, the method of diagnosis was clearly stated in 146 instances. The diagnostic methods are shown in Fig. 24.

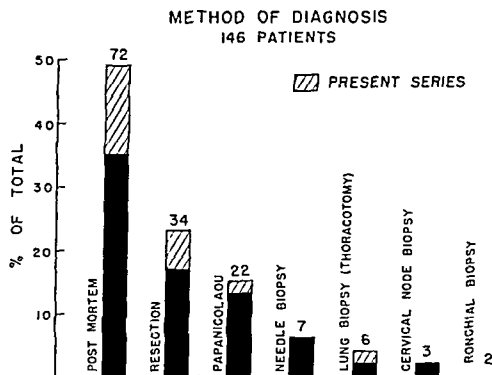


Fig. 24.

The increasing efficiency of the diagnostic methods now employed in patients with this malignancy is evidenced by the fact that although only one patient was diagnosed ante mortem prior to 1943, since that time at least 75 patients of record have been correctly diagnosed during life. The recent more frequent utilization of early excisional surgery in the management of patients with solitary peripheral nodules or persistent pulmonary infiltrates of uncertain etiology has resulted in a sharp increase in the number of patients diagnosed prior to death. Thirty-six patients with bronchiolar carcinoma have been diagnosed by histologic examination of the resected specimen.

By far the most promising of the newer diagnostic methods is cytologic examination of the sputum by the Papanicolaou technique. The first patient with this disease in whom the diagnosis of pulmonary malignancy was estab-

lished by this means was reported by Acevedo, Giuntini, and Croxatto⁶⁵ in 1944. The diagnosis was made in 1942 and was subsequently confirmed at autopsy. Hatfield and Hill⁶⁶ reported a patient with bronchiolar carcinoma in 1949 in whom the Papanicolaou stain was positive for malignant cells and again the post-mortem findings were confirmatory. In the same year Smith, Knudston, and Watson⁶⁷ reported 4 patients with bronchiolar carcinoma in whom the Papanicolaou was Class V. Two of those patients were diagnosed in 1947 and two in 1948. Since that time, 16 additional patients, including 3 reported here, with proved bronchiolar carcinoma have been accurately diagnosed as having pulmonary malignancy by cytologic examination of the sputum.^{10, 52, 58, 68-70} In other reported cases, the Papanicolaou has been strongly suggestive of cancer.^{55, 58}

Papanicolaou⁷¹ has noted that this tumor exfoliates profusely and yields abundant material characteristic of this type of neoplasm. Good and associates¹⁰ and McDonald and Woolner⁷² also feel that in certain instances cells in the sputum possess characteristics that will permit the examiner to suggest the diagnosis of bronchiolar carcinoma. The typical findings consist of clumps of columnar cells with a free border of cytoplasm and fairly regular nuclei. These are felt to consist of groups of cells representing papillary projections which have broken off and been expectorated. Fried³⁵ and others have commented upon the loose attachment of the abnormal cells lining the alveoli and the ease with which they become detached. In a case mentioned but not reported in detail by McCoy,⁵² the specific diagnosis of bronchiolar carcinoma was suggested by Dr. Papanicolaou on the basis of the sputum findings and that diagnosis was verified following resection of the lesion. The value of this diagnostic method is further emphasized by the report of Watson and Smith.⁵⁸ The sputum of 15 patients who proved to have bronchiolar carcinoma was studied. In 9 the sputum was positive for malignancy and in 3 it was strongly suggestive of cancer. Thus in 80 per cent of this group the sputum was either definitely positive or highly suggestive of carcinoma. These findings emphasize the necessity of repeated careful cytologic examination of the sputum of patients suspected of having this disease.

Among the other diagnostic methods, needle or aspiration biopsy, lung biopsy at open thoracotomy, and peripheral lymph node biopsy have each established the diagnosis in a small percentage of cases. Aspiration biopsy would appear to be indicated only in far-advanced cases with extensive pulmonary consolidation. Thoracotomy and lung biopsy without further resection has been used in patients with widespread bilateral disease. Patients with lesions of this type are doomed if the biopsy shows bronchiolar carcinoma; the justification for its use lies in the hope that some condition will be found in which effective therapy can be instituted. Bronchial biopsy would not be expected to yield positive results in this disease which characteristically does not involve the larger bronchi. However, in patients in whom the disease process is far advanced, the bronchi may be secondarily involved and a chance biopsy may show histologic evidence of the tumor. Such was the case in the 3 reported patients in which a positive bronchial biopsy was obtained.^{10, 58}

DISTRIBUTION OF DISEASE

When the information was available, the distribution of the disease within the lungs was determined on the basis of the interpretation of the patient's first chest roentgenograms showing the lesion. These data were correlated with the operative findings in those patients who were treated surgically. In the remainder, the distribution was determined on the basis of post-mortem examination. The results are shown in Fig. 25.

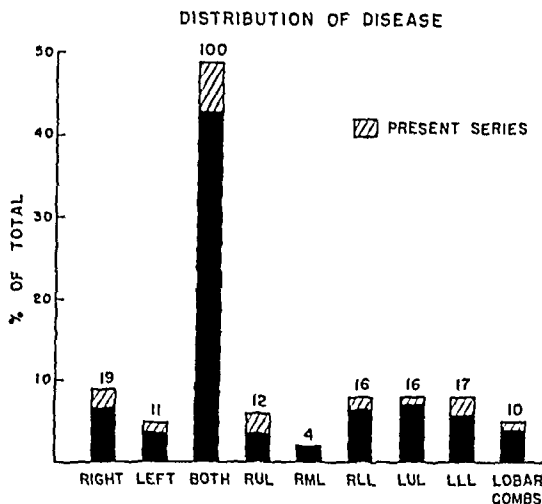


Fig. 25.

It will be noted that approximately 50 per cent of the patients had bilateral disease at the time that its extent was determined. However, these figures are weighted by the fact that information concerning the patient's chest x-ray films was not available in many cases (there were 52 such instances among the 205 patients). Under those circumstances the location of the lesions was determined at autopsy. When the involvement was unilateral the right and left lungs were affected with approximately equal frequency (51 and 44 times, respectively). There was no significant difference in the frequency of involvement of the various lobes. The figures on this graph do not agree with the distribution of this neoplasm as determined radiographically (Fig. 23). However, this graph is based on a larger series of patients, including many of the earlier cases in whom the diagnosis was established exclusively at autopsy.

METASTASES

The records of 168 reported patients and of the 37 patients in the present series, a total of 205, were reviewed from the standpoint of metastases. A summary of the findings is given in Figs. 26, 27, and 28.

Neubuerger and Geever¹⁷ have stated that metastases occur in approximately 50 per cent of patients and that in about one-half of those showing metastases, the secondary deposits will be confined to the mediastinal nodes.

Their estimate of the incidence of metastases is confirmed by our findings. One hundred ten (54 per cent) of the cases reviewed showed metastatic lesions. In 38 patients (35 per cent of those with metastases) there was local spread only, and 40 patients (36 per cent of the metastatic group) showed both local and distant spread. Thus 71 per cent of those with metastases, or 38 per cent of the entire group of 205 patients, had involvement of the intrathoracic lymph nodes. An extremely interesting and important observation is that 32 patients, 29 per cent of those with metastases, or 15.6 per cent of the entire group, showed *distant spread only*. This demonstrates the frequency of blood-borne metastases.

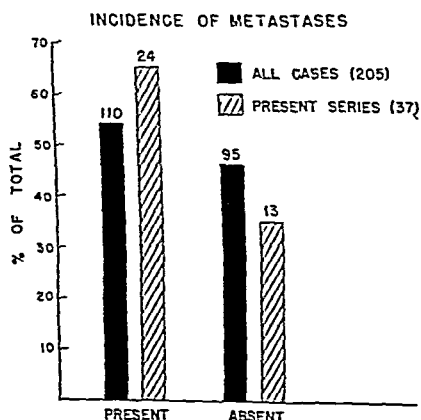


Fig. 26.

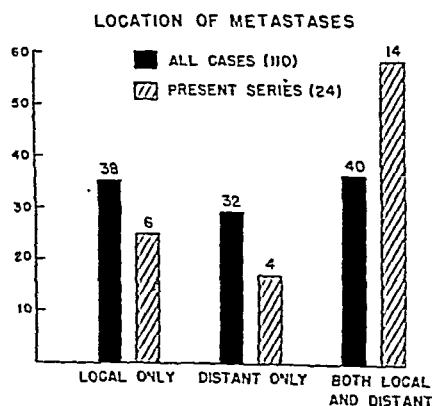


Fig. 27.

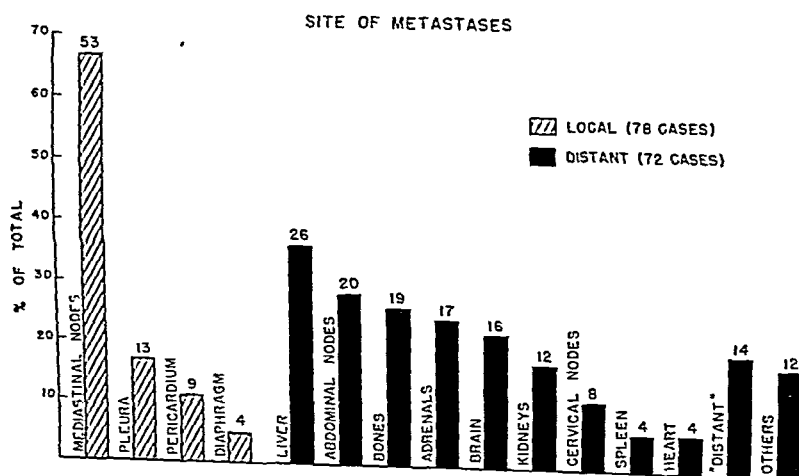


Fig. 28.

Four routes of spread are recognized: (1) local invasion by contiguity, (2) lymphatic, (3) blood stream, and (4) bronchiogenic dissemination. Local extension is universally recognized and it is not unusual for this tumor, which

frequently attains a massive size, to extend locally until an entire lung is involved. In these cases the pulmonary architecture is well preserved despite the total involvement with tumor. This finding is in distinct contrast to the growth characteristics of carcinoma of bronchial origin, a neoplasm which is typically destructive in nature. It has been predicated that in bronchiolar carcinoma the tumor spreads from alveolus to alveolus by way of the pores of Cohn.^{19, 20, 73} Lymph-borne spread is undisputed, having been established in 38 per cent of 205 patients. We have repeatedly observed tumor emboli in the pulmonary lymphatics, as have Fried,³⁵ Silverman and Angrist,²⁰ Laippley and Fisher,³² and many others. The perivascular and peribronchial lymphatics are found to be dilated and often filled with tumor cells. The evidence to support the occurrence of metastases by the blood stream is unequivocal. We have been able to demonstrate malignant cells in the pulmonary vascular channels and similar findings have been recorded by Fried,³⁵ Laippley and Fisher,³² Tillett and Hirsch,⁷¹ and Gepts.⁷⁵ Thirty-five per cent of 205 patients showed distant metastases. The liver, abdominal nodes, bones, adrenals, brain, and kidneys were the most frequent sites of distant spread, in that order. It is clear that these distant metastases were most often blood borne. There remains for consideration the question of bronchiogenic dissemination or so-called aerial metastases.^{19, 59, 73, 76} This matter is of critical importance in a consideration of these tumors. If this thesis is accepted, it will readily explain the frequency of bilateral lesions, with spread from a primary focus in one lung to the opposite lung, often without involvement of the mediastinal lymph nodes.

The theory of multicentric origin of these new-growths, which has never been adequately substantiated despite intensive study by many pathologists over a long period of years,^{10-12, 35, 12} might be abandoned if the concept of spread via the air passages can be proved. Conviction that these tumors arise unicentrically would make it logical to offer patients with this disease a far more hopeful outlook than that which they are now accorded. Furthermore, acceptance of aerial metastasis as a frequent means of spread would probably influence the type of surgery performed in patients with this tumor. It has been shown that 46 per cent of patients with bronchiolar carcinoma have no metastases, even at the time of death. An additional 15.6 per cent show *distant metastases only*, and 19.5 per cent demonstrate both local and distant spread. Eighty-one per cent of all patients therefore would receive no real lasting benefit from radical surgery of the type customarily employed in treating carcinoma of bronchial origin. Bronchiogenic cancer of course behaves in quite a different manner. In that neoplasm, spread to the mediastinal nodes is commonly an early finding and almost invariably occurs sooner or later. Metastases to the opposite lung, on the other hand, is rather infrequently seen. Schuster⁷⁶ has observed that it is only to be expected that malignant cells should be inspired into the air spaces and there set up multiple deposits on the alveolar walls. Silverman and Angrist²⁰ studied two cases of bronchiolar carcinoma and concluded that the tumor nodules dispersed throughout the parenchyma were obviously metastatic. Watson and

Smith²⁵ stated that metastases were most frequent to the same lung, the opposite lung or hilar nodes. Others^{27, 28} have expressed the same opinion. Frissell and Knox²³ have mentioned the possibility of spread by bronchiogenic dissemination as have many others. Papillary projections which break off easily are characteristic of this disease and the loose attachment of the tumor cells lining the alveoli has been repeatedly demonstrated. The fact that they desquamate and are coughed up has been proved numerous times by studies of the sputum by the Papanicolaou method.^{29, 32, 33, 34} Herbut¹⁶ has been one of the strongest proponents of the unifocal origin of bronchiolar carcinoma and has offered evidence to support his position that is difficult to refute.

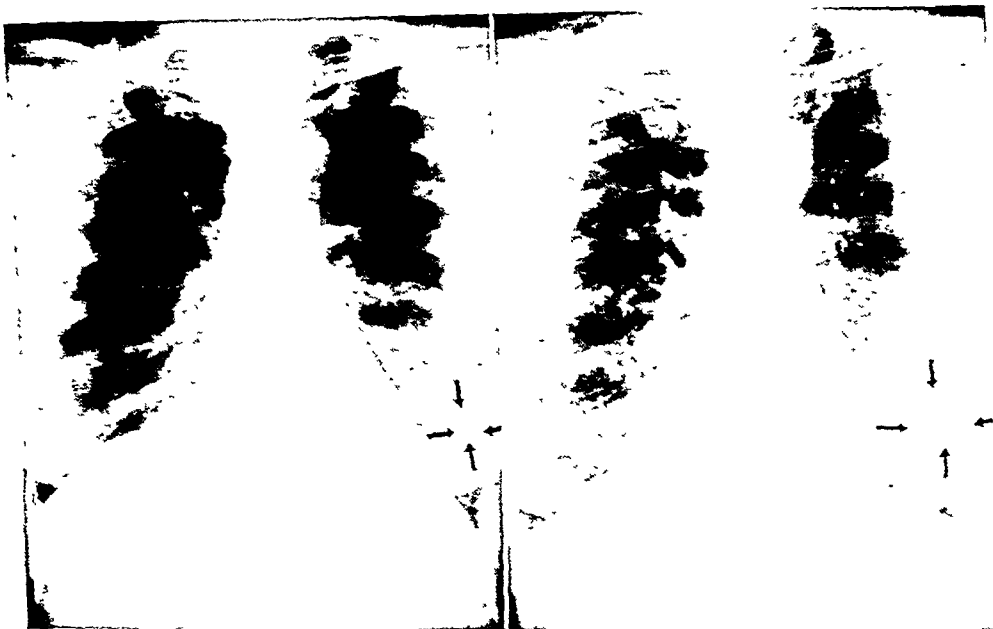


Fig. 29.

Fig. 30.

Fig. 29.—Chest x-ray film of a 72-year-old white woman made in 1946 showing a small but definite infiltrate in the left lower lung field.

Fig. 30.—Chest roentgenograms of the same patient made in 1950. The lesion seen in Fig. 30 has definitely increased in size but remains well localized. Resection of the left lower lobe showed bronchiolar carcinoma. The patient is alive and apparently well three years later.

Stewart²⁴ questions the apparent multiple origin of bronchiolar carcinoma and believes that multiple foci are due rather to lymphatic spread from a single focus with subsequent lining of lung acini. Weller²² is of the same opinion. Tillett and Hirsch²³ have been able to demonstrate the source of malignant tumor emboli which spread to both lungs by way of the pulmonary artery. They concluded that the concept of a multicentric origin of these tumors of the lung should be discarded. There are gross and microscopic features in this disease, however, that make it difficult if not impossible to explain all metastases on the basis of either blood-borne or lymphatic dissemination. In a painstaking study recently reported, Hutchinson¹⁵ offers

convincing evidence that the distribution of the tumor within the lung is determined by the air passages. He feels that the case which he studied in minute detail "not only establishes the extra-alveolar origin of some, at least, of the group of so-called alveolar-cell tumors but prove also that these growths may metastasize via the air passages." Aerial metastases, in addition to spread by the blood and lymph channels, appears to be a much more logical explanation of the behavior of this neoplasm than the unproved theory of multicentric origin. The late appearance of new lesions in the same or opposite lung following unilateral subtotal pulmonary resection or in the contralateral lung after total pneumonectomy can by no means be accepted as proof of a new primary lesion. One patient reported in this series presented conclusive x-ray evidence of a lesion four years before it was resected (Figs. 29 and 30) and proved to be a bronchiolar carcinoma. Even at the time of resection it was small and localized. How long it was present before its demonstration by chest roentgenograms is of course indeterminate.

Another patient's lesion, a small, circumscribed, peripheral nodule, remained stable at least twenty months and quite possibly considerably longer (Fig. 1). The known duration of the disease has been at least seven or eight years⁶³ and probably longer (eleven to fifteen years) in a number of cases.^{62, 79} In view of the frequent indolent behavior of these lesions, it would not seem illogical to assume that tumors which make their appearance months or years following resection usually represent metastatic lesions which were present but undetected at the time of operation rather than having arisen *de novo*.

TREATMENT

Until very recently, the diagnosis of bronchiolar carcinoma was made only at autopsy. In the rare case in which it was established during life, the disease was usually far advanced and only symptomatic and supportive treatment were employed. Numerous patients in the past have been erroneously diagnosed as having tuberculous and treated for that disorder; the true nature of the illness was revealed only at post-mortem examination. Irradiation and cytotoxic agents, such as nitrogen mustard, have been used in a few cases without proved beneficial results. Most authors who have reported upon the use of x-ray therapy have stated that it is completely useless in this malignancy.^{15, 50, 51} Within the past few years, resection has been employed with increasing frequency. This can be attributed to more accurate diagnostic methods, particularly cytologic studies of the sputum in patients with this disease, and to an increasing tendency on the part of the profession to advise prompt thoracotomy in space-occupying pulmonary lesions of uncertain etiology. There is a mounting awareness that "unresolved pneumonia" often means cancer and a laudable decrease in the tendency of physicians to "watch" undiagnosed pulmonary infiltrates that could reasonably represent carcinoma.

As a result of this aggressive policy, 49 patients with this rather uncommon pulmonary carcinoma have been treated by resection within the past seven years. Hope for patients with this lethal disease lies exclusively in early excisional surgery. In order that resection may offer reasonable pros-

pects of a cure, operation must be undertaken while the tumor is still localized and before the correct diagnosis may be made or strongly suspected on clinical grounds. If one waits until the clinical picture which some have considered as classic or typical is presented, the patient's fate is sealed. The mode of metastases of this tumor might well influence one to perform limited resection when surgery is undertaken. Whether it is of multicentric origin or arises in a single focus from which it may spread, it does not seem logical to advocate total pneumonectomy for bronchiolar carcinoma except in those patients where the unilateral distribution of the lesions makes that operation mandatory. If this malignancy does take origin from multiple primary foci, the advisability of employing surgery at all in its management might well be questioned.^{14, 19}

That very question has been, in fact, raised before the American Association for Thoracic Surgery in the recent past.⁵⁰ If, on the other hand, it is of unicentric origin and spreads by bronchiogenic dissemination as well as by more conventional routes, it would be difficult to defend a policy of routine radical surgery in its management. If an undetected metastasis has occurred prior to operation, the surgeon cannot divine the site to which the tumor has spread. It has been shown that but 19 per cent of patients with this disease will show metastases confined to the mediastinal nodes, while almost as many (15.6 per cent) will show distant spread only and 19.5 per cent will have both local and distant metastases. It is of course not possible to determine the percentage of spreads to the opposite lung, not yet visible by x-ray examination, which will have occurred at the time of excisional surgery. In view of the high percentage of patients who ultimately show bilateral pulmonary involvement, there seems to be little doubt that this circumstance will occur rather frequently.

Although we have treated one patient by segmental resection who shows no evidence of recurrence one and one-half years later and Watson and Smith⁵⁵ report a patient who is alive and well more than five years after "V" excision of a bronchiolar carcinoma, the frequency with which we and others^{13, 17, 56, 67} have found tumor involvement of the pulmonary lymphatics have led us to conclude that lobectomy is the treatment of choice in these patients when the distribution of the disease makes that operation feasible. There appears to be ample reason, in view of the nature of this tumor and the manner by which it appears to spread, to restrict resection of localized bronchiolar carcinoma to a reasonable minimum. The presence of mediastinal nodes showing histologic evidence of malignancy on examination of frozen sections in a patient without clinical or radiographic evidence of spread elsewhere would obviously call for a total pneumonectomy and radical mediastinal node dissection. Fig. 31 shows the treatment employed in 155 patients. Of the 49 patients who have undergone resection, 24 have been treated by lobectomy; pneumonectomy has been performed in 18; segmental resection in 4 and local enucleation in 3. Right lower lobectomy was performed at the original operation in one case but the tumor recurred three years later and the remainder of the right lung was removed. One of the lobectomy patients

underwent bilateral operations, a left upper lobectomy being followed after a short interval by right upper lobectomy and local resection of a segment of the right lower lobe. One of the patients treated by segmental resection of an upper lobe segment also had local enucleation of a rounded lesion from the lower lobe on the same side. That patient had a recurrence in the lower lobe four months later and lower lobectomy was performed for the recurrent lesion.

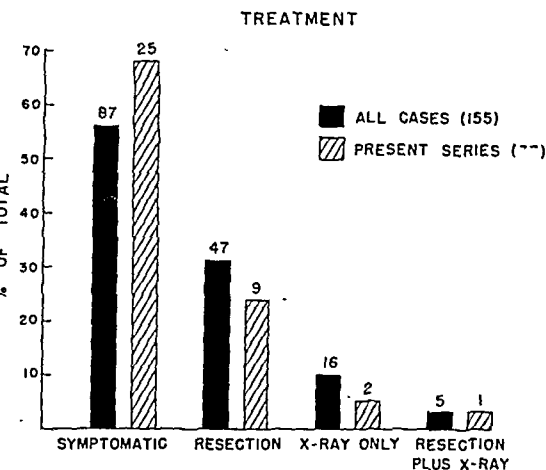


Fig. 31.

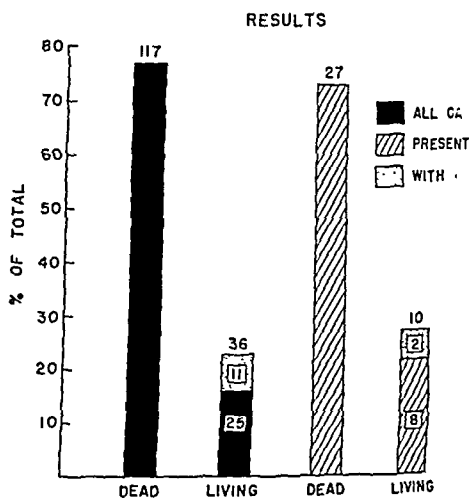


Fig. 32.

Investigation of the fate of the 49 patients who had resections reveals that those who have been treated by lobectomy or lesser operation have fared somewhat better than those who underwent pneumonectomy. The patients who had conservative surgery no doubt constituted a more favorable group with generally smaller more localized lesions. We are certain of 5 patients who are alive and well more than five years after resection; 2 of these have been reported by Watson and Smith,⁵⁸ and one case each by Skorpil,⁶⁰ Osserman and Neuhof⁸¹ and Delarue and Graham.⁴⁰ Four of these patients were managed by lobectomy and the other had a wedge resection. Graham's patient later had the remaining lobes of the right lung removed. Two patients in our series who were treated by lobectomy are alive and well over three years postoperatively, and one man who had a segmental resection is clinically and radiographically free of disease one and one-half years after surgical treatment.

RESULTS

Information as to the results of treatment was available in 153 of the 155 patients who were analyzed from the standpoint of therapy. The results are listed in Fig. 32.

In this graph, patients have been listed as living and well or living with disease on the basis of the last follow-up information. The fatal course of bronchiolar carcinoma is clearly shown by the fact that 77 per cent of the

patients have already died and death from the disease is anticipated in at least an additional 7 per cent. It is important to remember, however, that potentially effective therapy has been employed in patients with this neoplasm only in very recent years.

FOLLOW-UP

An attempt has been made to obtain follow-up information on the 36 surviving patients. The available data are tabulated in Fig. 33.

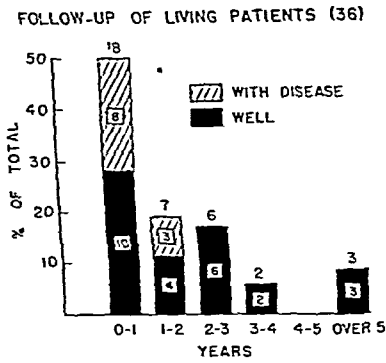


Fig. 33.

Recent follow-up information has not been available on many patients. The survival time listed in this graph is dated from the time of operation or other treatment to the date of the last follow-up. The most interesting finding in the follow-up study was the fact that all of the patients living with disease fell into the group who had been followed two years or less after surgical treatment. None of the patients followed longer than two years showed recurrent or persistent disease. This would suggest that recurrent tumors lead to a fatal termination within less than two years and, conversely, that patients who survive without evidence of disease for more than two years are likely to remain well. The number of patients followed is too small, of course, for definite conclusions to be drawn.

SUMMARY

The literature pertaining to an unusual pulmonary neoplasm, known variously as bronchiolar carcinoma, pulmonary adenomatosis, alveolar-cell tumor, alveolar-cell carcinoma, and by numerous other similar terms, has been reviewed. The histogenesis, pathology, clinical features, diagnosis, and treatment have been discussed. Thirty-seven hitherto unrecorded cases of this entity are reported. The reports of 120 patients with bronchiolar carcinoma which have appeared in the literature since the article by Swan¹² have been abstracted. One hundred eight of the collected cases and the 37 cases reported herein have been statistically analyzed. The essential data on the 37 patients reported herein are included in Table I. Similar data on the 120 patients collected from the literature are to be found in Table II.

TABLE I. STORL,

ND DATE	AGE	RACE	SEX	DURA- TION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
o. 143162	53	W	M	6	Anorexia, vomiting. Pain in head, neck, shoulders	Cherry-sized lesion in right upper lobe and right lower lobe	Amount not noted. Not examined
o. 167099	77	W	F	12	Intermittent dyspnea and fatigue for 12 mo. Nonproductive cough. Pain in right shoulder	Complete clouding of right lung	Not examined
Hospital, Ile, Ky.	53	W	M	5	Dyspnea. Lower chest pain, bilateral	Miliary soft infiltra- tions in both lung fields	Fungus isolated 1 wk. prior to death. Nega- tive for AFB
o. 189063	53	W	F	3	Onset Jan. 1947 with pain in chest and dyspnea; cough with copious frothy sputum. Dec. 1946 nausea and vomit- ing, anorexia and weight loss	Disseminated miliary- like patches throughout all lung fields	Negative for TBC. Crypto- coccus found
o. 206491	60	W	M	60	Onset 1942 with cough, occasional hemoptysis dyspnea on exertion; inter- mittent dull, left- sided chest pain	Opacity in lingula of left upper lobe	Negative for TBC
o. 215026	40	W	M	1	Hemoptysis, dyspnea, pain in right chest. Cough, severe, be- came paroxysmal, more blood, then better. One month later symptoms re- turned and patient went downhill	Right hydropneumo- thorax. Only air- bearing tissue in right apex	Negative for AFB, fungus and Papanico- lau negative
o. 186230	35	W	M	4	Gradual onset of right chest pain posteriorly, cough, dyspnea, excessive fatigue, weight loss. Tentative diagnosis: tubercu- losis, then changed to malignancy when wine colored fluid obtained from chest	Pleural effusion right hemithorax obscur- ing lung markings	Negative for AFB
o. 204693	65	W	M	7	Cough, dyspnea, sputum streaked with blood (copious amount of sputum, yellowish-white). Anorexia and his- tory of hemoptysis and ASCVD with myocardial infarc- tion	7 cm. mass in left lower lobe with atelectasis. Emphy- sema, left upper lobe	Smear and cul- ture neg. re- peatedly for AFB and fungi

, AND LAWRENCE

OF IS	AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
	Bronchiolar carcinoma	Right lower lobe	Right hilar nodes, pia-arachnoid, medulla and cord	Insulin and diet (for diabetes). Supportive. Irradiation (head)	Adm. 4/26/45 Died 5/23/45
	Bronchiolar carcinoma	Entire right lung. Primary was in right apex	Chest wall, hilar nodes, heart	Supportive only	Adm. 11/1/45 Died 12/15/45 (Prev. Hosp. in Aug. '45. Diag.: Neurofibroma)
	Bronchiolar carcinoma	All lobes, both lungs	Hilar lymph nodes	Supportive	Adm. May, 1946 Died 6/17/46
	Bronchiolar carcinoma	All lobes, both lungs	None	General therapy. Two 125 r x-ray irradiations	Adm. 2/26/47 Treatment: 250 roentgen u. Died 3/3/47
	Bronchiolar carcinoma	Lingula, left upper lobe	None	Left thoracotomy and amputation of lingula	Alive with no evidence metastasis Jan. '50
ny psy	Bronchiolar carcinoma	Right middle lobe almost solid. Nodule in upper and lower lobes, rt.	Pleura bilaterally. Tracheobronchial lymph nodes	Rt. thoracotomy, inoperable, closed. Supportive therapy	Adm. 8/1/47 Home with inoperable Ca 3 mo. Re-adm. 1/12/48. Died 1/15/48
	Bronchiolar carcinoma	Right lung, all lobes	Supraclavicular, paratracheal and hilar lymph nodes; liver, both adrenals, kidneys, cerebrum, skin (abdominal wall), retroperitoneal and mesenteric lymph nodes	Investigative studies incl. biopsy of cervical node and skin nodule on ant. abdominal wall. Supportive therapy	Adm. 12/28/46 Died 3/12/47
	Bronchiolar carcinoma	Upper and lower lobes. Predominately in left lower lobe	Pleura, supraclavicular, mediastinal, and hilar lymph nodes	Supportive therapy. Treated for CVD and infarction	Died three mo. after admission

TABLE

DATE AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
B. F.I.P. cc. No. 211674 47	52	W	M	4	Increasing cough, weight loss, shortness of breath, and recent onset of weakness and fever. Pneumonia and tuberculosis diagnosed first, then changed to malignancy	"Consolidation right base and innumerable nodular densities throughout both lung fields"	Negative for AFB
J. M. F.I.P. cc. No. 289061 48	39	W	M	11	Sudden onset of left pleuritic pain, chills, fever and cough (rusty sputum). Improved on bed rest and penicillin but 11 mo. later noted cough, weakness, large amounts sputum, dyspnea	Large amount fluid on left. Extensive mottling on right at level of second, third, and fourth interspaces. Aeration in apex right upper lobe, and middle lobe	Repeatedly negative for AFB. Up to 7 pints per day. Hemolytic strep. culture
J. S. F.I.P. cc. No. 217750 48	42	W	M	2	Progressive shortness of breath and dull aching in rt. lower chest. Pt. visited T.B. center. X-ray showed pulmonary path., then admitted to hosp.	On Adm.: Heavy nodular infiltration widely scattered throughout both lung fields. Subsequent: Incr. in nodular infiltration	Negative for AFB, fungus. Papanicolaou negative
P. B. F.I.P. cc. No. 260163	61	W	M	12	Coughing up blood. Cough for one yr., nonproductive at first but later increasing cough productive of reddish sputum. Weight loss, weakness, anorexia	Density in left upper chest suggestive of malignancy. Suspicious lesion in right upper lobe also	Repeatedly negative smear and culture for AFB
E. P. F.I.P. cc. No. 317202 948	57	W	M	30	Progressive orthopnea and weight loss. Dyspnea, productive cough. Pain right scapula, right lower chest and right upper quadrant	Extensive infiltration through entire left lung and almost complete collapse of right lung. Pneumothorax, rt. Fractured tenth rib, right midaxillary line	Papanicolaou negative on several occasions. Sputum negative for AFB
T. T. F.I.P. cc. No. 285263 949	61	W	M	24 to 36	Increasing shortness of breath, weakness, morning cough productive of 1-2 tablespoons yellowish sputum. In 6 mo., increasing weakness, 35 lb. weight loss, more productive cough, anorexia	Mild bilateral emphysema. Extensive reticulated and cavity infiltrations in left upper lobe and right lower lobe	15 cultures negative for AFB

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Bronchiolar carcinoma	Right lower lobe	Hilar and medias- tinal lymph nodes, scalp, liver, skeletal of skull T ₁ .	Pneumonia treated with penicillin; fever disappeared with incr. dysp- nea and down- hill course: Sup- portive therapy	Died two mo. after admission
Bronchiolar carcinoma	All lobes: LLL solid, others— nodules $\frac{1}{2}$ cm. to 3 cm.	None	"5 deep x-ray treatments to ant. chest." Iodides, aciri- flavin, penicillin for fungus	Respiratory death 17 days after admission
Bronchiolar carcinoma	All lobes	Peribronchial and periaortic nodes. Both kidneys	Supportive	Died two mo. after admission
Bronchiolar carcinoma	Left upper lobe	Left anterior chest wall and second left rib anteriorly. Heart, liver, spleen, intestines, adrenals, kidney, and mesen- tery	Supportive	Died 6 days after admission
Bronchiolar carcinoma	All lobes, bi- lateral	None	Palliative	Died 20 days after admission
Bronchiolar carcinoma	Left upper and lower lobes, lower pre- dominantly (none in right lung)	Hilar lymph nodes, left	Streptomycin, 1 Gm. q6h for 15 days. Aureomy- cin, penicillin, streptomycin for peritonitis	Died 2½ mo. after adm. of in- testinal obstruc- tion

DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
203244	73	W	M	8	Hacking cough (paroxysmal 5-10 days apart), productive of slight mucoid, blood-streaked sputum. Severity and frequency of cough increased, dyspnea, low-grade fever, left pleuritic pain, and weight loss one mo. prior to admission	Infiltration of left lower lobe. Probable 2.5 cm. mass below left bronchus	Negative for AFB. No other organisms cultured
276201	23	W	M	8	Increasing shortness of breath; 4 mo. later noted weakness and dyspnea and dull pain in right lower chest anteriorly (later on left also). Weight loss and cough with moderate whitish sputum, occasionally blood streaked	On admission: Fluid, right; nodules, left. Later: Density, right middle lobe, nodules all other lobes. Moderate-sized cavity, left upper lobe	Negative for AFB and fungi. No Papanicolaou recorded
269237	59	W	M	4	Sharp low back pain, weakness, 40 lb. weight loss, nocturia, nausea and vomiting; chronic cough with very little sputum	Chest x-ray showed circumscribed density in left lower lobe. Spine films showed destruction of L-2	Negative for acid-fast bacilli. Positive Papanicolaou for malignancy
spital, N. Y. 4	37	W	M	10 days	Cough (dry) for 6-7 months. Slight ache in chest (anterior) of indefinite duration	2 cm. density of left upper lobe in third interspace	Negative for acid-fast bacilli
296049	54	W	M	2	Abdominal pain; ulceration of left foot	Homogeneous density in region of left lower lobe. Mass in apex of left lung	Negative for acid-fast bacilli
264139	75	W	F	31	Cough, dyspnea, expectoration, loss of weight, anorexia	Triangular area of infiltration opposite right hilum; smoky infiltration, lower three-fourths, left chest	Clear, watery. Negative for AFB and fungi
276486	40	W	M	4	Shortness of breath, weakness, weight loss	Entire left chest obscured by homogeneous density; scattered rounded shadows throughout right lung	Meager amount. Positive Papanicolaou
337939	72	?	F	—	No symptoms. Accidental discovery on routine x-ray	Round nodule 4.5 cm. None in diameter, posterolateral aspect, right lower lobe	

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Bronchiolar carcinoma	LLL. Large nodule compressing bronchus. Diffuse nodular involvement of rest of lobe (lt. lower with areas of necrosis)	Liver and vertebrae (L-1 and L-2)	Considered for x-ray irradiation but none given	Died 3 wk. after admission of respiratory death
Bronchiolar carcinoma	All lobes, both lungs	Pleura, pericardium, diaphragm, liver, both kidneys, lt. adrenal, cerebral and cerebellum meninges, third lumbar vertebra; peribronchial, peritracheal, periaortic and perigastric lymph nodes	Supportive	Died one mo. after admission
Bronchiolar carcinoma	Left lower lobe	Hilar and mediastinal nodes, all lumbar vert., both adrenals, liver, kidneys, gut, esophagus, spinal cord, brain and meninges	Supportive	Died 9 mo. after admission
Bronchiolar carcinoma (my)	Left upper lobe	None	Thoracotomy, lt., with lt. upper lobectomy (curative)	In good condition 6 mo. later
Bronchiolar carcinoma	Left lower lobe	Regional tracheobronchial and bronchial nodes, bilateral adrenals, cerebral and cerebellar regions	Palliative	Died 5½ mo. after admission
Bronchiolar carcinoma (y)	Indefinite (see x-ray report). Apparently both lungs	Data not available	Supportive only	Died
Bronchiolar carcinoma (an. bron- edle)	Both lobes, lt. lung solid tumor, wt. 1,100 Gm. All lobes rt. lung contain innumerable round, discrete nodules, wt. 1,275 Gm.	None	Palliative	Died 1¾ mo. after admission
Bronchiolar carcinoma	Lateral segment, left lower lobe	None	Left lower lobectomy	Well with neg. chest x-ray 3 yr. P.O.

TABLE 1.

DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
03099	57	N	M	?	Mild dyspnea, right-sided chest pain, productive cough, mild anorexia, generalized weakness	Infiltrating lesion of right upper lobe	Negative for AFB, fungus and malignant cells
07704	67	W	M	?	Persistent cough	"Indefinite" infiltration of right upper lobe	Negative for malignant cells
08751	60	W	M	1	Head cold followed by severe cough and dyspnea, productive of $\frac{1}{2}$ cup yellowish-gray sputum; no hemoptysis. Had to sleep in sitting position. 15 lb. weight loss. Local doctor bronchoscoped and found malignant cells	Small area of clouding just above and lateral to superior portion of right hilum. Lateral view shows consolidation in basal portion of right upper lobe	Negative for AFB. Positive for malignant cells
97974	58	W	M	1	Mental confusion, speech difficulty, and irritability for one mo.	None taken	Negative for malignant cells
19700	71	W	M	7	Pain in flank, chest, and shoulder on right. Paroxysmal cough productive of thick, copious sputum, occasionally blood streaked; weight loss, febrile episodes, weakness, and incr. dyspnea	Homogeneous density in lower half of right lung field	Negative for AFB and malignant cells
11563	52	W	M	2-3 wk.	Hemoptysis (8 days prior to admission). Slight dyspnea on exertion. 10-12 lb. weight loss	Area relative uniform density, lower $\frac{1}{4}$ left lung field; bronchial margins partially visualized	Neg. for AFB. (2 exam. of bronchial secretion neg. for cancer cells)
pital, N. Y. 3	24	W	M	4	Burning sensation under right scapula, 4 mo. Dry cough for 2-3 mo. Low back pain with radiation to right leg, 4 mo.	Nodular density in third right interspace 10/21/50. Similar findings on film of 6/21/49. Read as negative	Neg. for AFB. Several suspicious Paps. (Class III)
07136	27	W	M	24	Dry cough for 2 yr.; dyspnea with generalized pains over entire body	Rounded density in right mid-lung field short distance from hilum	Three 24-hour sputum specimens negative for neoplastic cells
07262	54	N	M	16	Cough productive of blood-streaked sputum. Weakness, dyspnea, left chest pain, weight loss	Diffuse and extensive nodular infiltration both lungs, more marked on right	Amount not stated. Not examined for AFB or malignant cells
08899	45	W	M	4 $\frac{1}{2}$	Productive cough, loss of weight, easy fatigue	Complete opacity of entire left lung field	"Much." Negative for AFB

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Bronchiolar carcinoma	Right upper lobe	Hilar lymph nodes extensively involved	Thoracotomy, right with right pneumectomy	No cough, spu- tum, dyspnea, 2 mo. P.O.
Bronchiolar carcinoma	Right upper lobe	None	Thoracotomy with right upper lobe lobectomy	
Bronchiolar carcinoma	Right upper lobe	None	Thoracotomy, right with pneu- mectomy	Alive 1½ yr. P.O.
Bronchiolar carcinoma	Right lower lobe (periphery)	Brain, hilar lymph nodes	Craniotomy but no tumor found	Died one day P.O.
Bronchiolar carcinoma	Right middle lobe, right lower lobe, right upper lobe	Parietal pleura, mediastinum, epi- cardium, both adrenals	Palliative and symptomatic therapy	Died 14 days after admission
i- Bronchiolar carcinoma	Left lower lobe	None	Left lower lobe lobectomy	Symptom free last follow-up
Bronchiolar carcinoma	Right upper lobe	Heart, liver, kidneys and spine	Thoracotomy, right, with biopsy. Suppor- tive, with x-ray to spine	Died 4½ mo. after admission
Bronchiolar carcinoma	Right hilar re- gion of right lung	Osteolytic lesion, left ilium	Rt. pneumonec- tomy. X-ray treatment to left ilium	Alive with meta- static disease
Bronchiolar carcinoma	All lobes, both lungs, worse on right	Tumor was seen in lymphatics and blood vessels of lung	Digitalis. Peni- cillin	Died 12 hr. after admission
Bronchiolar carcinoma	Both lungs: lt. solid. Wt. lt.— 1,300 Gm. Wt. rt.—850 Gm.	Ribs, dorsal spine, pericardium, dia- phragm, liver. No positive nodes	O ₂ , antibiotics, streptomycin, blood trans- fusions	Died 41 days after admission

TABLE I.

PATIENT AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
33. L. S.† Mound Park Hospital, St. Petersburg, Fla. No. T-7504 1951	63	W	F	24	Chest pain, 2 yr. debility, weakness, emaciation, nonpro- ductive cough	Dense opacification, left lung. Bilateral pleural effusions (bloody)	Sputum and pleural fluid repeatedly neg. for AFB. Sputum pos. for atypical cells. Pap. Class III
34. B. S. H. Naval Hospital, St. Albans, N. Y. No. 120251 1951	44	W	M	10	No symptoms. Dis- covered on routine chest x-ray, Dec., 1950. In April, 1951 developed pro- ductive cough and pain, right upper chest, anteriorly	Small, smooth, round, circumscribed lesion, 2.5 cm. in diameter, anterior segment, right upper lobe	8 sputum cul- tures neg. for AFB. Papanic- olaou not done
35. C. H. B.‡ V. A. Hospital, Seattle, Wash. No. 67-715 1951	74	W	M	?	Dyspnea, motor aphasia. Right hemiplegia	Small irregular in- filtrations scattered throughout lower one-half of left lung	Gastrics nega- tive for AFB. (Patient was not rational and sputum could not be collected.)
36. N. L. F.§ Naval Hospital, Portsmouth, Va. No. 127237 1952	42	W	F	9	No symptoms. Dis- covered on routine chest x-rays. Later developed slight dyspnea on exertion	Diffuse bilateral millinodules, all lobes, both lungs	Negative for AFB. Papanic- olaou nega- tive. Negative for fungi
37. J. H. Naval Hospital, St. Albans, N. Y. No. 130549 1952	23	W	M	31	Productive cough, repeated small hemoptyses, right chest pain, 9 pound weight loss	Large rounded homo- geneous density in right lower lobe; irregular small homogeneous den- sity in anterior seg- ment, right upper lobe	Small amount of mucoid sputum with several small hemoptyses; later: 60 c.c. mucoid sputum daily with occ. blood

*Case included through the courtesy of Drs. Harold Gordon, J. R. Gott, Jr., and R. A. Switzer.

†Case included through the courtesy of Drs. E. B. Campbell, Sr., and E. B. Campbell, Jr.

‡Case included through the courtesy of the Medical Director, United States Public Health Service Hos-
pital, Seattle, Wash.

§Case included through the courtesy of Drs. Charles Ferguson and Paul Spangler, U. S. Naval Hospital,
Portsmouth, Va.

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Bronchiolar carcinoma	Both lungs. Pleura dia- phragm, peri- toneum	Pleura, diaphragm, peritoneum, mesen- tery	Supportive and symptomatic only	Died 4 mo. after admission
Bronchiolar carcinoma	Anterior segment, right upper lobe. Hilar nodes neg.	None	Segmental resec- tion anterior segment, right upper lobe	Well 18 mo. after resection
Bronchiolar carcinoma	Left upper lobe, small foci, left lower lobe	1. Brain—2 foci, left cerebral hemi- sphere. 2. Posterior pituitary (?).	Symptomatic. Penicillin, oxy- gen, etc.	Died approxi- mately two mo. after admission
Bronchiolar carcinoma	All areas, all lobes, both lungs. (Extensive pleural invol. many nodules)	None	Symptomatic	Adm. 3/24/52. Still in hospital. Disease rap. progress
Bronchiolar carcinoma	Medial basal seg- ment, right lower lobe and an- terior segment, right upper lobe METASTASES	None evident at operation. Nodes negative. Recur- rence in right lower lobe 4 mo. later	Segmental resec- tion anterior seg., RUL and local enucleation of lesion, RLL. Right lower lobectomy for recurrent lesion four months after original operation	No evidence of disease at present (9 mo. after second operation)

TABLE 11.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
1. Skorpil ⁶⁰ 1941	34	W	M	About 30 mo.	Sensation of pressure in left chest	A spherical, homogeneous shadow, size of a mandarin, seen in the middle of left lung field next to upper portion of hilum. Thought to represent metastatic spread to hilar nodes from a small primary lesion barely visible in upper lobe	1 episode of hemoptysis
2. Acevedo, Giuntini, and Croxatto ⁶⁵ 1942	50	W	F	14 mo.	Weakness, anorexia, dyspnea on exertion, slight cough productive of yellow sputum, orthopnea	Multiple nodular soft confluent densities in right lung. 6 mo. later: Lt. hydro-pneumothorax with no change on right side. Also had homogeneous opacity, lower and middle portions, left lung field	Mucopurulent, viscous and transparent sputum up to 1,500 c.c. daily
3. Fernandez Luna and Bracco ⁶¹ 1943	62	W (Argentinian)	M	8-9 mo.	Febrile episode (grippe) with much sputum. Pain in right upper chest, cough, sputum, weight loss	Opacity, right upper hemithorax with cavitation in mid-lung field	Purulent, copious, bloody. Free AFB by smear and G.P. inoculation
4. Wenger ⁷ 1945	60	W (Bolivian)	F	Several mo.	Cough of several mo.; 1 mo. prior to death, cough increased, febrile. 15 days before death, intense cough and high fever	Not done	Not mentioned
5. Couch, Fleming, and Harrison ⁸² 1945-47	48	W	F	Unknown	Pain in shoulder and lumbosacral region	Not done	Not recorded
6. Rey and Rubinstein ⁸⁶ 1947	62	W	M	8½ mo.	Cough, mucopurulent, viscous, and transparent sputum up to 1,500 c.c. daily. No fever and general health unchanged. No weight loss	Localized lesion in right base, and incr. lt. hilar shadow. Last x-ray 1 mo. prior to death showed increase of right basal and left hilar process	Small quantity of yellow-green sputum
7. Silverman and Angrist ²⁰ 1948	31	W	F	6 mo.	Pleuritic pains, right chest. Shortness of breath and cough	Initially, evidence of consolidation of the right lower lobe, later involvement on the left side also	Character not stated. "Scanty"

CASES

F S	AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
	Alveolar epithelial carcinoma	Peripherally in left upper lobe	None	Left upper lobe lobectomy	Alive and well 5 yr. later
psy	Bronchorrheal form of gelatinous cancer of the lung	Right lower lung field and left hilar region	None noted (no autopsy)	Symptomatic	Dead
m	Pseudopneumonic pulmonary cancer (Ewing's diffuse alveolar cancer)	Right lung	None	None	Dead
m	Alveolar-cell tumor	All lobes, both lungs	Liver	None	Dead
m	Alveolar-cell tumor	2 by 2 cm. nodule in LUL	Liver, both adrenals, brain and vertebrae	Symptomatic	Dead 3 mo. after adm.
au	Pulmonary adenomatosis	Entire right lung and lower half, left lung	None	Symptomatic	Dead
tem	Lobar adenocarcinoma	Bilateral	Hilar nodes, adrenal glands, kidney	None	Dead

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
8. Silverman and Angrist ²⁰ 1948	73	W	F	2 mo.	Cough and bloody sputum	Increased density lower half rt. lung, incr. density and prominent radiating shadows upper lobe rt. lung, prominent bilateral hilar shadows. 2 wk. later: Radiating shadows entire rt. lung, prominent bilat. hilar shadows, nodular infiltrations throughout rt. lung. <i>Pleural eff., rt.</i>	Bloody
9. Hildebrand ²³ 1948	66	W	F	9 mo.	Cough and clear sputum	Bilateral pulmonary involvement	Large quantity clear frothy sputum, late stage
10. Jennings ⁵⁹ 1948	58	W	F	10 mo.	Onset: dry cough; subsequently frequent colds and grad. incr. dyspnea. Later: cough, sputum, pleuritic pain, dyspnea, 10 lb. wt. loss; hemoptysis last 2 mo. of life	Mottling in both upper zones and opacities at bases with lat. fading. Patch of density in mid-zone of rt. lung, coarse mottling on left. Lower parts of lungs resembled confluent bronchopneumonia	Much purulent sputum. Later: more frothy profuse, still purulent. Hemoptysis later
11. Jennings ⁵⁹ 1948	56	W	M	12 mo.	Chills, fever, left chest pain, cough, slight hemoptysis, left-sided pleurisy. 40 lb. wt. loss	Coarse patchy mottling all zones rt. lung with incr. vascular pattern. LUL clear, LLL opaque, medial zone of density	Purulent, slightly bloody
12. Drymalski, Thompson, and Sweany ^{30*} 1948	34	W (Polish)	F	About 14 mo.	On first adm: non-productive cough, 4 lb. wt. loss. 9 mo. later: bronchopneumonia with fever (105°), hemoptysis, right lower chest pain	Routine x-ray few mo. prior to first adm: 3 cm. cavity in RLL. X-ray after penicillin during first adm: some clearing of the soft infiltrate about cavity wall. 6 mo. after first adm: no changes in comparison with prev. chest films. About 14 mo. from first x-ray (on second adm.): Consolidation and atelectasis of RLL	Initially non-productive. Hemoptysis
13. Drymalski, Thompson, and Sweany ^{30*} 1948	55	W	F	6 mo.	4 mo. prior to adm: developed mild cough. On adm: cough, small amount sputum occasionally streaked by blood; fatigue, weakness. Later: became progressively more dyspneic and weaker	On adm: Areas of marked haziness in both lungs, most pronounced in the right. Cardiac shadow was displaced to left	Small amt; occasionally blood streaked. 1 mo. prior to death: positive for Ca

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Lobar adeno- carcinoma	Both lungs	None described	Symptomatic	Dead
Pulmonary adenomatosis	All 5 lobes of lungs	None	Supportive	Dead
Alveolar-cell tumor	All lobes of both lungs	Mediastinal nodes	Symptomatic	Dead
Alveolar-cell tumor	Lower lobes, both lungs	None	Symptomatic	Dead
Pulmonary adenomatosis	Right lower lobe	None	First adm: 1 mil- lion units of penicillin. Second adm: lobectomy	"P.O. course un- eventful." No follow-up
u m. le ag. n). m	Pulmonary adenomatosis	Both lungs in mid- zones; nodule be- neath pleura in rt. base	None seen (<i>lungs</i> only removed at post-mortem)	None recorded Dead

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
14. Drymalski, Thompson, and Sweany ³⁰ 1948	45	W	F	22 mo.	2 yr. prior to adm.: influenza for 3 wk. Fatigue, intermittent cough, usually nonproductive; 25 lb. wt. loss, poor appetite, failing strength. After adm: progressive severe dyspnea. 2 mo. prior to adm: pulm. hemorrhage of 10 oz.	17 mo. before admission: "Evidence of a pulmonary lesion." Later: marked hazy infiltration of right lung and of middle field of left lung	2 mo. before adm: pulm. hemorrhage of 10 oz. No malig. cells found. Cough was usually nonproductive
15. McCallum ³¹ 1948	52	W	M	18 mo.	Cough, frothy sputum, weight loss. Later: dyspnea, cyanosis, pleuritic chest pain, slight fever	Initially: density in the lt. lung, more marked in upper and middle zones. 6 mo. later: patchy opacities throughout whole lt. lung field. 17 mo. later: lt. lung solid, spread to RUL	Cupful daily, thin, frothy. Hemoptysis on occasion
16. Shipman, Stephens, and Binkley ³² 1949	51	W	F	8 yr.	Cough and sputum	Area of incr. density, roughly triangular in shape, lying just above the diaphragm and posterior to lower portion of major fissure. Bronchograms showed bronchiectasis, right lower lobe	Originally small amt. of clear, frothy, glairy mucoid sputum. Later: increasing amount, thick, yellow, foul
17. Laipply and Fisher ³² 1949	51	W	F	3 mo.	Difficulty in breathing, cough, and weakness	Slight passive congestion of both lungs	Not recorded
18. Laipply and Fisher ³² 1949	45	W	M	10 mo.	Pain in chest and cough, 9 mo. Worse recently with hemoptysis, shortness of breath, increasing chest pain, anorexia	Diffuse mottling in lung fields due to small areas of incr. density in all lobes of both lungs, esp. central regions and lower lobes	Bloody
19. Hatfield and Hill ³³ 1949	51	W	F	5 yr.	Dyspnea, cough, sputum, anorexia, fatigue, weight loss	Diffuse scattered nodular areas of incr. density, all areas both lungs. Films made 10 mo. previously showed large rounded oval area of incr. density, left base and scattered nodular areas, right base	Slight at first. Later increased. Positive Papanicolaou
20. Freedman ³³ 1949	29	W	F	9 mo.	Chest pain, cough, sputum, loss of weight, dyspnea	Bilateral disseminated nodular disease	Large quantities, thin, watery. Negative for AFB

	AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
	Pulmonary adenomatosis	Entire rt. lung; in lt. similar lesion fanned out from hilum and reached pleura lat. and base posteriorly.	None	Pneumothorax (discontinued after 1 yr.)	Dead
1	Alveolar-cell tumor of lung	Entire left lung, right apex and superior seg- ment, right lower lobe			
	Pulmonary alveolar adenomatosis	Right lower lobe	None noted at opera- tion	Right lower lobec- tomy	Living 9 mo. P.O. Areas of density in remaining right lung
em	Primary alveo- lar-cell tumor	All lobes, both lungs	None	Symptomatic	Dead
em	Primary alveo- lar-cell tumor	All lobes, both lungs	Pleura, intrapul- monary lymphatics, mediastinal and cervical nodes, left adrenal gland	Symptomatic	Dead
laou	Pulmonary adenomatosis	All lobes, both lungs	Hilar nodes None	Symptomatic	Dead
tem	Pulmonary adenomatosis	All lobes, both lungs	None	Treated for tuber- culosis	Dead

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
21. Bubis and Erwin ⁶ 1949	66	W	M	3 mo.	Chest pain, intermittent fever, severe cough and yellow sputum	Linear basal markings incr. bilaterally with considerable pneumonitis in these areas. Slight amt. left pleural fluid. Bronchograms: bilateral basal bronchiectasis	Yellow, mucoid
22. Bubis and Erwin ⁶ 1949	63	W	M	5 yr.	Cough, shortness of breath	Patchy opacity throughout lower three-fourths of rt. lung; large areas of consolidation mid-portion of left; apparently many fibrous strands along line of bronchial trunks, lower half, lt. lung. Radiologist's imp: Granulomatous, probably fungus	Moderate amounts
23. Effert ⁵⁵ 1949	68	W	F	8 yr.	Three episodes of pneumonia, 8, 7, and 6 yr., prior to death. Gradual downhill course with increasing dyspnea and cough. Overwhelming weakness 1 yr. prior to death	Innumerable, bilateral, rather symmetrical, somewhat confluent densities. Thought to represent massive hematogenous metastases from an unknown primary carcinoma	Amount and character not recorded
24. Liavaag ⁵⁶ 1949	83	W	F	5 yr.	Angina pectoris and cardiac failure. Admitted to hospital with diagnosis of cardiac infarction. Tumor was in very early stage; no clinical symptoms	Not done	None
25. King and Carroll ⁵¹ 1950	63	N	F	1 yr.	Cough and sputum	Diffuse involvement, more marked on left	Amount and type not recorded
26. King and Carroll ⁵¹ 1950	58	W	F	5 yr. 3 mo.	Severe cough, mucoid sputum, severe dyspnea	Mar. 1945: Patchy incr. density base LUL. Feb. 1947: Patchy pneumonia, LLL. June 1947: Patchy infiltrations, left. Oct. 1948: Patchy consolidation, LLL. Thereafter serial films showed slow but progressive involvement of both lungs by confluent nodular densities. LLL had been removed in Nov. 1948 and scattered nodular densities of LUL and RLL were noted by Dec. 1948.	None early in disease; later copious, mucoid

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Pulmonary adenomatosis	All lobes, both lungs	None	Sulfadiazine	Dead
Pulmonary adenomatosis	Both lobes, left lung: upper and middle lobes, right lung	None	Symptomatic	Dead
Primary diffuse alveolar epi- thelial car- cinoma	"Diffuse, penny- sized lesions, more or less symmetrical in both lungs"	Hilar nodes, liver, paraaortic nodes, lymph nodes in porta hepatis	None	Dead
Alveolar-cell tumor	Left upper lobe	None	None	Died second hosp. day (not due to tumor)
Pulmonary adenomatosis	All lobes, both lungs	None noted	Symptomatic	Dead
Pulmonary adenomatosis	Left lower lobe	None noted at opera- tion (autopsy not permitted)	Resection, left lower lobe; later irradiation, finally sympto- matic	Dead

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
27. King and Carroll ⁵¹ 1950	53	W	F	Less than 2 mo.	Shortness of breath, chest pain, generalized aches. Cough, copious sputum, anorexia, nausea, vomiting, weakness, weight loss	Innumerable soft nodular densities throughout both lungs. Nodules poorly outlined, more numerous in middle and lower lung fields where nodules became so confluent as to obscure the heart shadow	Thin, watery, frothy; as much as 1,000 c.c. in 24 hr.
28. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	54	W	F	12 mo.	Severe nonproductive cough	Area of consolidation in left lower lobe	None
29. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	34	W	F	7 mo.	Chronic cough, intermittent low-grade fever	Poorly circumscribed area, apparently pneumonitis, posterior to hilum in left lung	Meager, clear, whitish
30. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	62	W	F	6 mo.	Nonproductive cough	Pleural reaction around left hemidiaphragm, large area of consolidation in left lower lobe	Almost none. Papanicolaou positive
31. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	47	W	F	4 yr. (?)	Chronic cough, sputum occasionally blood tinged	Area of pneumonitis in left lower lobe	2 yr. before adm: severe prod. cough; bloody on 1 occ. On adm: clear, watery
32. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	53	W	M	18 mo.	Chronic productive cough	Dense hemispherical mass in right chest occupying lower three-fourths of right hemithorax	Frothy white; blood on 1 occ. Papanicolaou negative
33. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	30	W	F	1 yr.	Chronic productive cough	Dense irregular mass in left lower lobe; smaller irregular patch in right upper lobe opposite hilum	Gray mucoid, occasionally blood streaked. Positive Papanicolaou, probably alveolar-cell carcinoma
34. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	55	W	F	2 yr.	Chills, fever, cough with some blood	Area of pneumonitis in the lingula	Cough nonprod. until just before adm. when she raised some blood. Papanicolaou positive, thought to be of alv. cell type
35. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	49	W	M	4 mo.	Chronic productive cough, 12 lb. wt. loss. Fever abated following penicillin	Elevation of lt. hemidiaphragm, fluid in rt. pleural space, poorly circumscribed mass in superior portion of RLL	½ cup daily, yellow. Papanicolaou positive
36. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	57	W	M	6 mo.	Dyspnea and weakness on exertion, occasional nonproductive cough	"Generalized, diffuse tuberculosis of both lungs"	None

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Pulmonary adenomatosis	All lobes, both lungs	None	Symptomatic	Dead
Alveolar cell tumor	Left lower lobe	None	Resection, left lower lobe	Dead
Alveolar-cell tumor	Left lower lobe	None	Lobectomy, left lower lobe	Died of Hodg- kin's dis. 2 yr. P.O.
Alveolar-cell tumor	Left lower lobe	None	Lobectomy, left lower lobe	Living 2 yr. P.O.
Alveolar-cell tumor	Left lower lobe	None	Lobectomy, left lower lobe	Good immed. re- sult. Contact lost
ny Alveolar-cell tumor	RML voluminous. Many nodules in upper and lower lobes	None at operation	Right pneumonec- tomy	Lesion in left lung 7 mo. later
Alveolar-cell tumor	Left lower lobe, right upper lobe, right lower lobe	None	Lobectomy, LLL. Lobectomy, RUL. Seg. resection, portion of RLL	Dead of rt. heart failure sixth P.O. day after second operation
Alveolar-cell tumor		None	Lobectomy, left upper lobe	Clinically well 6 mo. P.O.
Alveolar cell tumor		None	Pneumonectomy, right	Well (recently op. uneventful P.O.)
Alveolar cell tumor	All lobes, both lungs	None	Symptomatic	Dead

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
37. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	44	W	F	11 mo.	Productive cough and dyspnea on exertion	Large mass in left lower lobe, many nodules throughout both lungs	Watery, sometimes yellow, occasionally foul. Bloody on few occasions
38. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	56	W	M	2 yr.	Chronic cough, dyspnea on exertion. Substernal pain for 3 mo.	Poorly defined mass in right lung. Many nodules scattered throughout both lungs	Occasional blood
39. Good, McDonald, Clagett, and Griffith ¹⁰ 1950	46	W	M	3½ mo.	Shortness of breath and weakness. Productive cough	Diffuse nodular lesions involving all lobes of both lungs, sparing only the apices and costophrenic angles	Character not recorded
40. Weir ¹⁵ 1950	63	N	F	1 yr.	Cough, copious sputum, night sweats, 20 lb. wt. loss	Conspicuous density in lower half of right lung field involving almost all of left	About "a quart" daily; clear, watery, frothy
41. Weir ¹⁵ 1950	58	W	F	44 mo.	Sweats, left subcostal pleuritic pain, cough and sputum, vomiting	Mar. 1947: density in lt. base resembling unresolved pneumonia. 1947: infiltration in left lower lung field interpreted as chronic pneumonitis. 1948: same	Purulent, later frothy. 207 c.c./day. None early in disease
42. Weir ¹⁵ 1950	53	W	F	7 wk.	Cough with copious sputum, weakness, anorexia, weight loss, nausea, vomiting	Miliary nodules throughout all lobes, both lungs, most dense at hilar regions	"Coffee can full" of watery, foamy sputum daily. Neg. for AFB
43. Davis and Simon ⁹ 1950	83	W	F	1 mo.	Shortness of breath, increasing fatigue, anorexia	Irregular conglomerated areas of increasing density involving the greater part of both lung fields	None
44. Davis and Simon ⁹ 1950	70	W	F	2 yr.	Chronic cough, profuse expectoration, 15 lb. wt. loss, irregular fever 1 mo. prior to adm.	Infiltrative process throughout both lungs with cyst formation in some areas. 1 wk. later: extension of pneumonia on both sides with considerable LLL by more chronic disease and considerable involvement of RUL by a new process.	Profuse. Negative for AFB
45. Davis and Simon ⁹ 1950	57	W	F	21 mo.	Right chest pain, dull. 5 lb. wt. loss. Later: constant hacking cough and increasing pleuritic chest pain	This was interpreted as lung cyst with infection. Infiltrative process in RML. Bronchography showed incomplete filling of bronchial tree in RML, other bronchi normally outlined. 6 wk. later: complete opacity of right lower chest	None when admitted. 6 wk. later: faint blood-streaked sputum

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Alveolar-cell tumor	All lobes, both lungs	Regional nodes and adrenals	Irradiation	Dead
Alveolar-cell tumor	All lobes, both lungs	None	None	Sudden death 10 days after ad- mission
Alveolar-cell tumor	All lobes, both lungs	Hilar nodes and liver	None	Died 4 days after adm.
Pulmonary adenomatosis	All lobes, both lungs	None mentioned	Supportive	Dead
Pulmonary adenomatosis	Left lower lobe and lingula	Not stated	Lobectomy, left lower lobe	Ret'd. 5 mo. P.O. coughing inces- santly. 1,183 c.c. sputum daily. Died shortly
Pulmonary adenomatosis	All lobes, both lungs	None mentioned	Symptomatic	Dead
Alveolar-cell tumor	All lobes, both lungs	None	Symptomatic and supportive; peni- cillin	Dead
Alveolar-cell tumor	All lobes, both lungs. Both lower lobes and about 1/4 of each upper lobe con- solidated	None	Penicillin, amino- phylline for pul- monary edema, digitalis	Dead
Alveolar-cell tumor	All lobes of right lung	Autopsy not done. Questionable vis- ceral and parietal pleural metastasis	Penicillin and supportive	Died about 9 mo. after explor. thoracotomy

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
46. Davis and Simon ⁹ 1950	75	W	F	1 mo.	Productive cough and dyspnea. 15 lb. wt. loss (had been on reducing diet). Later: cyanotic, neck veins engorged, lethargic	Mottled infiltration throughout entire right lung and similar process in upper portion of left lung	Moderate amounts, white, foamy. No AFB on culture
47. Davis and Simon ⁹ 1950	78	W	F	2 yr.	Dyspnea 2 yr. Chest cold 2 mo. Severe dyspnea on adm., pain in left chest, ankle edema, engorgement of neck veins, cyanosis	Not done	Bloody on several occasions
48. Moyer ⁸⁷ 1950	37	W	F	3 mo.	Cough, increasing malaise, dyspnea	Adm: increased lung markings, all lung fields. Flocculent, structureless density, rt. lower chest which obscured all lung markings. 1 mo. later: lesion in lt. base, similar to rt. Later spread to involve entire left lower lobe	Yellowish-white, frothy, small amount. Negative for AFB, fungi, etc
49. Gagnés ⁶⁸ 1950	37	W	M	14 mo.	Productive cough	Homogeneous opacity from rt. hilum to rt. base. 2 yr. later: rt. costophrenic sulcus had become obliterated and opacity had appeared at lt. hilum. 1 yr. later: most of both lung fields were involved	Character not recorded. Neg. for TBC. No Pap. until 2 yr. after lesion found; alv.-cell Ca. recognized
50. Paul and Juhle ⁶⁹ 1950	48	W	F	9 mo.	Cough, copious sputum, chest pain, dyspnea, chronic fatigue	Marked density, basal half, lt. lung field. Mottled density in lt. mid-lung; upper $\frac{1}{4}$ clear. On rt., homogeneous density, lower $\frac{1}{4}$, upper lobe, patchy and stringy density from hilum along rt. cardiac border to the medial base. 8 mo. later: bilateral advance of disease	Copious, clear, watery
51. Paul and Juhle ⁶⁹ 1950	67	W	M	4 mo.	Severe, persistent cough, copious sputum	Homogeneous density paralleling lt. cardiac border and extending from hilum down toward the base. 8 mo. P.O.: increase in homogeneous density bilaterally with almost complete consolidation of central and basal lt. lung field; similar findings involving all of right lung except upper $\frac{1}{4}$	Original mucoid, later blood tinged. Terminal phase: "several pints" daily, clear, watery. Papanicolaou showed "abnormal cells"

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Alveolar cell tumor	Both lungs, all lobes	None	Symptomatic and supportive	Dead
Alveolar cell tumor	Both lungs	None	Supportive	Dead 1 day after adm. Art. scl. heart dis. and cardiac failure
Pulmonary alveolar adenomatosis	All lobes, both lungs	None	Symptomatic	Dead
Alveolar epi- thelioma of lungs, pul- monary pseudoadeno- matosis	Bilaterally diffuse terminally. Right lower lobe initially	None	Symptomatic	Dead (about 3 yr. after adm.)
Pulmonary adenomatosis	All lobes, both lungs	None	None	Died during lung biopsy, 16 mo. after onset
Pulmonary adenomatosis	Originally left lower lobe. Later: all lobes both lungs	Pleural at least	Left lower lobec- tomy; no treat- ment of recur- rence and/or spread	Moribund 4 mo. after adm. Probably dead

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
52. Paul and Juhl ⁶⁹ 1950	42	W	M	Not stated	Severe productive cough; pain in left hip	Rounded mass of soft tissue density overlying upper mediastinum. Wedge-shaped areas of conglomerate density in both central and basal lung fields; triangular shadow on rt. at medial base. Bone destruction, left hip	6-8 ounces daily, tenacious, yellow
53. Paul and Juhl ⁶⁹ 1950	42	W	M	2 mo.	Chronic, productive cough. 50 lb. wt. loss in 2 mo.	Homogeneous density obscuring middle $\frac{2}{3}$ lt. lung field. Bronchography showed multiple cavities communicating with lingular bronchus. 6 mo. P.O.: widespread mottled density, right lung	Foamy, thick, yellow-white, no blood. On standing would separate into upper foamy and bottom watery layer. One pint daily
54. McCoy ⁵² 1951	60	W	M	14 mo.	Marked dyspnea; severe, paroxysmal coughing, productive	Deviation of tracheal and mediastinal shadow to rt.; diffuse, mottled infiltrate, bilateral, extending peripherally from the central lung fields. 14 mo. previously: numerous bilateral parenchymal deposits	Clear, thin, frothy
55. McCoy ⁵² 1951	31	W	F	1½ mo.	Dyspnea on exertion, mild nonproductive cough	1 wk. before adm: resembled military tuberculosis. Adm. films: diffuse mottling throughout both lungs most dense in the hilar areas and radiating well out into the periphery. Subsequent x-rays showed confluence of lesions	None. Papanicolaou positive, Class V
56. Peterson and Houghton ¹⁴ 1951	59	W	M	4 or 5 yr.	Increasing cough, marked fatigue	Lt. hemidiaphragm elevated, several circumscribed areas of infiltration in region of lingula, each measuring 1-2 cm. diameter	Hemoptysis once, productive cough
57. Peterson and Houghton ¹⁴ 1951	56	W	M	2½ yr.	Weight loss, cough	Poorly visualized rt. lung obscured by marked shift of mediastinum to rt.; generalized incr. density and atelectasis. Moderate infiltration in all parts of this lung and similar process apparent on the lt. with exception of the apex	Not stated

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Pulmonary adenomatosis	Right lung only	Pericardium, hilar nodes, liver, adrenals, sternum, ilium	X-ray to bone lesion, hip	Dead
Pulmonary adenomatosis	Originally left lung. P.O.: spread to entire right lung	None at operation	Pneumonectomy, left	Moribund from spread to entire right lung
Alveolar-cell carcinoma	All lobes, both lungs	Liver, tracheobron- chial nodes	Symptomatic	Dead
Alveolar-cell carcinoma	All lobes, both lungs	Hilar nodes, vertebral bone marrow	Nitrogen mustard without benefit	Died of respira- tory insuffi- ciency (36 days after adm.)
Pulmonary adenomatosis	Lingula	None	Segmental resec- tion, lingula	No evidence of recurrence 28 mo. later
Pulmonary adenomatosis	All lobes, both lungs	None described	Nitrogen mustard, streptomycin, no benefit	Dead

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
58. Gepts ⁷⁵ 1951	72	W	F	2 mo.	Dyspnea, dry cough	Not described	None
59. Kent ⁴⁹ 1951	40	W	M	4 yr.	Cough 4 yr. 2 mo. cough worse, sputum. Dyspnea, lassitude	Extensive patchy consolidation throughout rt. lung with patchy collapse, posterior basal segment, RLL. Appearance suggests an old inflammatory lesion with superadded bronchiectasis rather than carcinoma. Left lung normal	½ oz., mucoid, morning
60. Kent ⁴⁹ 1951	54	W	M	8 mo.	Right pleural effusion, sterile and blood stained. Increasing dyspnea, cough with scanty sputum, 8 lb. wt. loss	Rt. pleural effusion, infiltration and cavitation rt. upper zone. Appearance that of tuberculosis, no radiologic evidence Ca	Scanty (bronchial aspirate neg. sterile)
61. Rosewood, Boucot, and Aegerter ⁸⁸ 1951	16	?	M	3½ yr.	No symptoms (discovered on photofluorogram taken for pre-employment application)	3½ yr. preop: photofluorogram showed small rounded mass with central area of rarefaction at lt. base (LLL). 2½ yr. preop: x-ray revealed no change; 2 mo. preop: increase in size of lesion	None; negative P.P.D. test, first strength
62. Voluter and Rywlin ⁸⁹ 1951	55	W	F	5 mo.	Symptoms of bronchitis with productive cough, asthenia, pallor, cachexia	Diffuse infiltration, right lower lobe. Emphysema; elevation, right hilum. Later: numerous nodules throughout all lobes, right lung, except extreme apex	Negative for AFB; Papanicolaou negative, pos. for Friedlander's
63. Bass and Singer ⁷⁹ 1951	59	W	M	15 yr.	Cough and sputum for 15 yr. Adm.: severe cough, dyspnea, weakness	Dense homogeneous opacity of rt. hemithorax with retraction of trachea and mediastinum to rt. Bullous emphysema, lt. upper lung. Mottled infiltration, lower ½, lt. lung field. X-rays during past 15 yr. showed multiple cystic areas with fluid levels	Purulent; negative for AFB, Papanicolaou not done

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Pulmonary adenomatosis	All lobes, both lungs	Hilar and supra- clavicular nodes, vertebral bodies	None	Dead
Alveolar-cell carcinoma	Right lung	None	Pneumonectomy, right	Died 24 hr. P.O. from pulmonary embolus
Alveolar-cell carcinoma	RUL replaced by a gelatinous hemorrhagic mass	Supraclavicular nodes only, left	None	Dead
Solitary pul- monary ade- noma (focal pulmonary adenomatosis)	Solitary tumor in LLL, near inter- lobar fissure directly beneath pleura	None	Local enucleation plus margin of lung tissue for biopsy	Alive and well 2¼ yr. P.O. No recurrence
Primary uni- lateral alveo- lar cancer of the lung	RLL solidified and contained cavity. Nodules, RML and RUL	Liver, spleen, and abdominal nodes	Symptomatic	Died shortly after adm.
Co existing lobar adeno- carcinoma and cystic disease of lung	Entire right lung	Mediastinal lymph nodes	Supportive	Dead

TABLE II

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
64. Abbott ⁵⁰ 1951	67	N	M	1 mo.	Severe cough, weakness, weight loss, râles and rhonchi	X-ray diagnosis: mycotic infection	Minimal, mucoid; malignant cells seen
65. Abbott ⁵⁰ 1951	60	W	F	6 wk.	Cough, weight loss, anorexia, dyspnea	X-ray diagnosis: lung abscess and bronchiectasis	Moderate, mucoid; Papanicolaou negative
66. Abbott ⁵⁰ 1951	60	W	F	3 yr.	Cough, dyspnea, weakness, anorexia, weight loss, fever	X-ray diagnosis: diffuse lung tumor	None
67. Abbott ⁵⁰ 1951	63	W	M	2 mo.	Cough, weakness, dizziness, blurring of vision, dyspnea, râles, dullness, friction rub over base of right lung	X-ray diagnosis: metastatic carcinoma or fungus infection	None
68. Abbott ⁵⁰ 1951	44	W	M	2 yr.	Cough, much sputum, weakness, fever, leukocytosis, pain in chest; impaired resonance, moist râles, increased tactile fremitus	Not recorded	Copious, jelly-like
69. Kennamer ⁵¹ 1951	39	W	M	13 mo.	Weakness, dyspnea, large sputum production. Onset was with pleuritic pain, fever	Originally: lt. pleural effusion. Later: homogeneous density involving entire lt. hemithorax and lower 3/4 of right	Blood streaked. On 1 occ. 3.3 L. in 12 hr. Usually 2-3 pints daily. Neg. for AFB
70. Watson and Smith ⁵² 1951	62		M	9 mo.	Cough, chest pain	Multiple nodules	Not examined
71. Watson and Smith ⁵² 1951	35		M	2 mo.	Chest pain	Mass filling chest	Not examined
72. Watson and Smith ⁵² 1951	42		M	4 mo.	Dyspnea and dysphagia	Multiple nodules	Not examined
73. Watson and Smith ⁵² 1951	55		M	5 mo.	Cough	Hilar mass; peripheral nodule	Not examined
74. Watson and Smith ⁵² 1951	61		F	2 mo.	Cough	Solitary nodule; pleural effusion	Negative for tuberculosis
75. Watson and Smith ⁵² 1951	55		M	2 mo.	Loin pain	Hilar mass	Not examined
76. Watson and Smith ⁵² 1951	59		M	6 wk.	Chest pain	Hilar mass	Negative for tuberculosis
77. Watson and Smith ⁵² 1951	59		M	1 mo.	Dyspnea	Pleural effusion	Not examined
78. Watson and Smith ⁵² 1951	48		M	6 mo.	Back pain	Hilar mass	Not examined
79. Watson and Smith ⁵² 1951	47		F	6 mo.	Pneumonia	Solitary mass	Not examined

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Pulmonary adenomatosis and alveolar- cell carci- noma	Both lungs	Hilar nodes	None	Dead
Pulmonary adenomatosis and alveolar- cell carcinoma	Right upper and middle lobes	None	Pneumonectomy, right	Well 1 yr. P.O.
Pulmonary adenomatosis and alveolar- cell carci- noma	Both lungs	Hilar nodes and pericardium	None recorded	Dead
Pulmonary adenomatosis and alveolar- cell carcinoma	Both lungs	Hilar and aortic nodes, liver, and adrenal	None recorded	Dead
Pulmonary adenomatosis and alveolar- cell carci- noma	Both lungs	None	None	Dead
Pulmonary adenomatosis	Both lungs	None	Antibiotics and supportive	Dead
Terminal bronchiolar carcinoma	Left lower lobe	Yes. Location not recorded. "Distant"	X-ray	Died 11 mo. after onset of symp- toms
Terminal bronchiolar carcinoma	Scattered foci, entire lt. lung	Yes. Location not recorded. "Distant"	Symptomatic	Dead
Terminal bronchiolar carcinoma	Right lower lobe	Yes. Location not recorded. "Distant"	Symptomatic	Dead
Terminal bronchiolar carcinoma	Left upper lobe	Yes. Location not recorded. "Distant"	X-ray	Dead
Terminal bronchiolar carcinoma	Right middle lobe	Hilar nodes	X-ray	Dead
Terminal bronchiolar carcinoma	Left upper lobe	Hilar nodes and "distant"	X-ray	Dead
Terminal bronchiolar carcinoma	Left lower lobe	None	Pneumonectomy	Died 19 mo. P.O.
Terminal bronchiolar carcinoma	Entire left lung	Yes. Location not recorded. "Distant"	Symptomatic	Dead
Terminal bronchiolar carcinoma	Right hilar area	Yes "distant" (bone)	X-ray to bone	Died 11 mo. after onset of symp- toms
Terminal bronchiolar carcinoma	Right lower lobe	None	Lobectomy	Alive and well after 5 yr.

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
64. Abbott ⁵⁰ 1951	67	N	M	1 mo.	Severe cough, weakness, weight loss, râles and rhonchi	X-ray diagnosis: mycotic infection	Minimal, mucoid; malignant cells seen
65. Abbott ⁵⁰ 1951	60	W	F	6 wk.	Cough, weight loss, anorexia, dyspnea	X-ray diagnosis: lung abscess and bronchiectasis	Moderate, mucoid; Papanicolaou negative
66. Abbott ⁵⁰ 1951	60	W	F	3 yr.	Cough, dyspnea, weakness, anorexia, weight loss, fever	X-ray diagnosis: diffuse lung tumor	None
67. Abbott ⁵⁰ 1951	63	W	M	2 mo.	Cough, weakness, dizziness, blurring of vision, dyspnea, râles, dullness, friction rub over base of right lung	X-ray diagnosis: metastatic carcinoma or fungus infection	None
68. Abbott ⁵⁰ 1951	44	W	M	2 yr.	Cough, much sputum, weakness, fever, leukocytosis, pain in chest; impaired resonance, moist râles, increased tactile fremitus	Not recorded	Copious, jelly-like
69. Kenamer ⁵¹ 1951	39	W	M	13 mo.	Weakness, dyspnea, large sputum production. Onset was with pleuritic pain, fever	Originally: lt. pleural effusion. Later: homogeneous density involving entire lt. hemithorax and lower $\frac{3}{4}$ of right	Blood streaked. On 1 occ. 3.3 L. in 12 hr. Usually 2-3 pints daily. Neg. for AFB
70. Watson and Smith ^{58†} 1951	62		M	9 mo.	Cough, chest pain	Multiple nodules	Not examined
71. Watson and Smith ^{58†} 1951	35		M	2 mo.	Chest pain	Mass filling chest	Not examined
72. Watson and Smith ^{58†} 1951	42		M	4 mo.	Dyspnea and dysphagia	Multiple nodules	Not examined
73. Watson and Smith ⁵⁸ 1951	55		M	5 mo.	Cough	Hilar mass; peripheral nodule	Not examined
74. Watson and Smith ^{58†} 1951	61		F	2 mo.	Cough	Solitary nodule; pleural effusion	Negative for tuberculosis
75. Watson and Smith ^{58†} 1951	55		M	2 mo.	Loin pain	Hilar mass	Not examined
76. Watson and Smith ^{58†} 1951	59		M	6 wk.	Chest pain	Hilar mass	Negative for tuberculosis
77. Watson and Smith ^{58†} 1951	59		M	1 mo.	Dyspnea	Pleural effusion	Not examined
78. Watson and Smith ^{58†} 1951	48		M	6 mo.	Back pain	Hilar mass	Not examined
79. Watson and Smith ^{58†} 1951	41		F	6 mo.	Pneumonia	Solitary mass	Not examined

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Terminal bronchiolar carcinoma	Left upper lobe	None	"V" excision tumor	Alive and well after 5 yr.
Terminal bronchiolar carcinoma	Right and left lungs	Yes; location not recorded "distant"	Symptomatic	Died 6 mo. after onset of symp- toms
Terminal bronchiolar carcinoma	Left upper lobe	Yes; location not recorded "distant"	X-ray to metas- tasis	Died 16 mo. later
Terminal bronchiolar carcinoma	Left upper lobe	Yes; location not recorded "distant"	Symptomatic	Died 15 mo. later
Terminal bronchiolar carcinoma	Right upper lobe	Hilar nodes	Thoracotomy; in- operable	Died 6 mo. later
Terminal bronchiolar carcinoma	Right upper lobe	None	Pneumonectomy	Alive and well 26 mo. P.O.
Terminal bronchiolar carcinoma	Left upper lobe	Hilar nodes	Pneumonectomy	Died 9 mo. P.O.
Terminal bronchiolar carcinoma	Right lower lobe	Hilar nodes	Pneumonectomy	Died 6 mo. P.O.
Terminal bronchiolar carcinoma	Left lower lobe	Hilar nodes and "distant"	Symptomatic	Died 12 mo. later
Terminal bronchiolar carcinoma	Right lower lobe	Hilar nodes	Segmental resec- tion and radia- tion	Alive 8 mo. P.O. with dis.
Terminal bronchiolar carcinoma	Left upper lobe	Hilar nodes	Pneumonectomy	Alive and well 8 mo. P.O.
Terminal bronchiolar carcinoma	Entire left lung	Hilar nodes	Pneumonectomy	Died 4 days P.O.
Terminal bronchiolar carcinoma	Entire left lung	Hilar nodes and "distant"	X-ray	Alive 7 mo.
Terminal bronchiolar carcinoma	Right hilar area	Hilar nodes	Pneumonectomy	Alive 5 mo. P.O.
Terminal bronchiolar carcinoma	Right upper lobe	Yes "distant"	X-ray	Alive 3 mo. after treat.
Terminal bronchiolar carcinoma	Left upper lobe	None	Lobectomy	Alive 2 mo. P.O.
Terminal bronchiolar carcinoma	Right upper lobe	None	Pneumonectomy	Alive 6 mo. P.O.
Terminal bronchiolar carcinoma	Left lung	Yes "distant"	X-ray	Died 5 mo. after treat.
Terminal bronchiolar carcinoma	Right upper lobe	None	Pneumonectomy	Alive 3 mo. P.O.
Terminal bronchiolar carcinoma	Right hilar area	Hilar nodes	Thoracotomy; x-ray	Alive 3 mo.
Terminal bronchiolar carcinoma	Diffuse, both lungs	Yes "distant"	Symptomatic	Died 4 mo. later
Terminal bronchiolar carcinoma	Diffuse, both lungs	Yes "distant"	X-ray	Alive 3 mo. later

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
80. Watson and Smith ^{ss†} 1951	50		M	—	None	Infiltrative mass	Not examined
81. Watson and Smith ^{ss†} 1951	51		M	5 mo.	Pneumonia	Multiple nodules	Not examined
82. Watson and Smith ^{ss†} 1951	28		M	6 mo.	Shoulder pain	Mediastinal mass	Not examined
83. Watson and Smith ^{ss†} 1951	57		F	10 mo.	Pain, cervical spine	Pleural effusion	Not examined
84. Watson and Smith ^{ss†} 1951	39		M	4 mo.	Chest pain	Mediastinal mass	Papanicolaou Class III
85. Watson and Smith ^{ss†} 1951	62		M	1 mo.	Chest pain	Solitary mass	Papanicolaou Class V
86. Watson and Smith ^{ss†} 1951	58		F	1 mo.	Chest pain, wheezing	Solitary mass	Papanicolaou Class V
87. Watson and Smith ^{ss†} 1951	50		M	3 mo.	Virus pneumonia	Multiple nodules	Papanicolaou Class V
88. Watson and Smith ^{ss†} 1951	59		M	1 yr.	Dyspnea	Patchy density	Papanicolaou Class V
89. Watson and Smith ^{ss†} 1951	59		M	—	None	Solitary mass	Not examined
90. Watson and Smith ^{ss†} 1951	43		F	—	None	Solitary mass	Not examined
91. Watson and Smith ^{ss} 1951	57		M	3 mo.	Chest pain	Pleural effusion	Papanicolaou Class I, negative for TBC
92. Watson and Smith ^{ss} 1951	51		M	5 mo.	Chest pain	Pleural effusion	Not examined
93. Watson and Smith ^{ss} 1951	51		M	6 mo.	Cough	Hilar mass; patchy density	Papanicolaou Class V
94. Watson and Smith ^{ss} 1951	66		M	9 mo.	Cough	Hilar mass; atelectasis	Papanicolaou Class II
95. Watson and Smith ^{ss} 1951	50		M	5 mo.	Dyspnea	Solitary mass	Papanicolaou Class III
96. Watson and Smith ^{ss} 1951	52		F	?	Dyspnea	Solitary mass	Papanicolaou Class III
97. Watson and Smith ^{ss} 1951	62		M	1 mo.	Chest pain	Infiltrative mass	Papanicolaou Class I
98. Watson and Smith ^{ss} 1951	55		F	—	None	Solitary mass	Papanicolaou Class IV
99. Watson and Smith ^{ss} 1951	41		M	1 yr.	Cough	Hilar mass	Papanicolaou Class IV
100. Watson and Smith ^{ss} 1951	71		M	3 mo.	Chest pain	Multiple nodules	Papanicolaou Class IV
101. Watson and Smith ^{ss} 1951	56		M	1 mo.	Cough, chest pain	Multiple nodules; bilateral	Papanicolaou Class IV

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Terminal bronchiolar carcinoma	Right upper lobe	None	Lobectomy	Alive 3 mo. with- out disease
Pulmonary adenomatosis	Lower portions, both lungs	Not recorded	Irradiation with no diminution. Later nitrogen mustard with no apparent benefit	Present status unknown, prob- ably dead
Pulmonary adenomatosis	All lobes on right. Left upper lobe	Not recorded	Symptomatic	Died of respira- tory insuffi- ciency
Alveolar cell tumor of the lung	RML at operation. At post-mortem entire remaining right lung; about ½ of left upper lobe	Right cerebral hemi- sphere, 2 tracheo- bronchial nodes, 1 periaortic node, liver	RML lobectomy, followed by irradiation. Symptomatic treatment only for spread and recurrence 4 yr. later	Good palliation after lobectomy, 2½ yr. Then re- currence and death
Pulmonary adenomatosis	Right lung	None	Symptomatic	Dead

TABLE II.

AUTHOR AND DATE		AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
102.	Watson and Smith ⁵⁸ 1951	49		F	—	None	Solitary mass	Papanicolaou Class III
103.	Kern, Lewinsky and Curran ⁵⁵ 1952	65	W	M		Cough, fantastic amounts of sputum	Bilateral mottled densities in lower portions of both lungs and a confluent density massive, LLL. Mottled and confluent densities in lower $\frac{1}{3}$ of rt. lung and lower $\frac{1}{2}$ of left lung	Huge quantities, clear, frothy, mucoid. Strongly suspicious of pulmonary adenomatosis
104.	Dennis, Raby, and Hildenbrand ²⁸ 1952	51	W	M	8 mo.	Productive cough, shortness of breath, 30 lb. wt. loss; weak and emaciated, respirations loud and gurgling; had had chills and fever	Initially: homogeneous infiltration in periphery of RUL and in lt. base. 7 mo. later: Homogeneous consolidation of entire RUL, partial consolidation of rt. middle and lower lobes and the LUL	On adm: frothy, yellow resembling pale soapsuds
105.	White, Madding, and Hershberger ⁶² 1952	34	W	M	Probably 11 yr.	Productive cough, wt. loss of 35-40 lb. in one yr.	7 yr. preop: unresolved pneumonia, RLL. 4 yr. preop: RLL lesions had become more extensive. 1 yr. preop: disease more extensive in rt. chest and entire lt. lower lung field was involved. Time of op: Consolidation of rt. lower lung field and probable pneumonic process, LLL. 3 yr. P.O. The pulmonary process had become more extensive	Copious, thick, frothy, mucopurulent, streaked with blood
106.	Valentine and Wynn-Williams ²⁹ 1952	41	W	F	About 1 yr.	Lt.-sided pleurisy 15 yr. previously; Lt.-sided pneumonia on at least 4 occ. Cough, fever, sputum, dyspnea on exertion about 1 yr. 5 mo. after adm.: wt. had fallen 13 lb.; cough very troublesome. 8 mo. after adm: clubbing of fingers noted. 9 mo. severe dyspnea and pyrexia. 11 mo.: severe dyspnea, cyanosis, cough and frothy sputum	Extensive shadowing over the rt. lung, most marked in middle zone but also extending into the lower and slightly into the upper zones. The whole lt. lung field was opaque but in the upper and middle zones there were radiolucent areas of the type seen in cystic bronchiectasis. These shadows were seen to be an extension of those noted in films made 1 yr. prior to adm. 5 mo. after adm: extension of shadows on	1-2 oz., frothy; bloody on several occasions

AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
Pulmonary adenomatosis	Both lungs	None	Symptomatic	Dead
Pulmonary adenomatosis	Both lungs	Mediastinal and cervical nodes	None	Dead
Terminal bronchiolar or "alveolar- cell" carci- noma of lung	All lobes, both lungs	Hilar and para- tracheal nodes	Symptomatic	Died on 13th hospital day
Pulmonary adenomatosis	Right lower lobe	None	Right lower lobe lobectomy	Died at home 6 mo. P.O.
Alveolar-cell carcinoma	Both lungs. LCL completely con- solidated (prob- ably primary here)	Extensive lymphatic involvement. Glands at hilum. Lymphatic involvement along aorta into abdomen; surface of heart; right lobe of liver, kidneys, spleen	None recorded	Pt. gradually weaker, more dyspneic, pulse failed. Dead 22 days after adm.

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
107. Valentine and Wynn-Williams ²⁹ 1952	73	W	F	9 mo.	Increasing dyspnea, slightly productive cough	Dense shadowing over the lower and middle zones of the rt. lung, also slight mottling in the upper zone; some rounded densities in the upper and middle zones of lt. lung	Small amount, blood tinged
108. Valentine and Wynn-Williams ²⁹ 1952	80	W	M	"Sever- al" mo.	Shortness of breath on exertion, marked weight loss, progressive weakness: cough and sputum for 1 mo.	Slightly raised right hemidiaphragm, obscured costophrenic angle. Interlobar septum slightly thickened, moderate opacity of the middle zone, spreading slightly above and below it	Amount and character not noted
109. Dunham and Smith ⁷⁰ 1952	64	W	M	2 mo.	Dyspnea, orthopnea, chronic cough and hemoptysis, 2 wk. Progressive weakness and fatigability for 2 mo. Occasional chest pain	Widespread diffuse nodular lesions bilaterally with confluence in left mid-lung and right base	Pink tinged; Papanicolaou positive
110. Hutchinson ¹⁹ 1952	36	?	F	6 mo.	Easily tired, frequent cough, expectoration for 6 mo. At 5 mo. prior to adm: pneumonia for 1 mo.; never fully recovered; thereafter chest pain persisted. On adm: dyspneic even at rest, frequent cough	Ill-defined opacity in lower part of rt. lobe with some faintly defined nodular opacities in upper part of rt. lobe; RUL and other lung appeared normal. 3 mo. P.O.: X-ray evidence of involvement of both the remaining portions of rt. and left lungs	Strikingly large quantities; white, frothy (clear watery layer on standing)
111. Hutchinson ¹⁹ 1952	38	?	M	4-5 mo.	Persistent cough for 4-5 mo.; loss of weight, breathlessness, 2 mo.; sputum worse during this period. Blood-stained sputum for 10 days prior to adm. On adm: severe dyspnea and short hacking paroxysmal cough; emaciated and cachectic	Diffuse mottling of both lungs, more on left than right. Diagnosis: TBC? tumor?	"Worse" during 2 mo. before admission. Blood stained for 10 days prior to admission

OF S n	AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
	So-called pulmonary adenomatosis	Both lungs	None distant. (Blood vessels at periphery of lung, tracheo-bronchial lymph node.) Also intimal edge of branch of pulmonary artery	None recorded	Died on 5th hospital day
	Papillary carcinoma of the lung (so-called pulmonary adenomatosis)	Right upper lobe, right middle lobe	None by clinical evidence (necropsy not done). Tumor cells found in blood vessels	Right pneumonectomy	Died outside of hosp.
sy s- e-	So-called pulmonary adenomatosis	Left lung	None recorded (necropsy not done)	Left pneumonectomy	Died outside of hosp.
tesis; tem	Alveolar-cell carcinoma	All lobes, both lungs	Visceral and parietal pleura on rt.; visceral pleura on lt; diaphragm, hilar nodes (autopsy limited to thorax)	None recorded	Dead

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
112. Tillett and Hirsch ⁷⁴ * 1952	57	W	M	15 yr. ?	Chronic, nonprod. cough for 15 yr.; worse past 5 mo. 6 wk. prior to adm: cold with mod. severe cough productive of yellow-green phlegm. Anorexia for past 4 wk. 10 lb. wt. loss. Several days before admission: dyspnea with fever of 101° F.	Widespread infiltration of lung fields with a maximum involvement of the right upper lobe	6 wk. before admission: yellow-green phlegm
113. Tillett and Hirsch ⁷⁴ * 1952	57	W	M	3-4 mo.	3-4 mo. prior to adm: became dyspneic. About 1 mo. later: cough when lying down, productive of about a tablespoon of brown sputum daily (about 3 yr. before had a pneumonia which cleared uneventfully)	Atelectasis of right upper lobe and some involvement of the middle lobe	2-3 mo. before adm: about a tablespoon of brown sputum daily
114. Tillett and Hirsch ⁷⁴ * 1952	52	W	M	18 mo. ?	2 yr. before adm.: pleurisy of left chest. 1 yr. later: recurrence of this from which he never fully recovered. Gradually increasing shortness of breath for 18 mo. Occasional cough productive of copious white, frothy sputum which for 1 wk. had been streaked with blood. During 1 mo. before admission: almost constant chest pain	X-rays of G.I. tract were negative. X-ray of chest not recorded	"Copious," white, frothy. Streaked with blood for 1 wk. prior to adm.
115. Fisher and Holley ⁹⁰ *	80	W	F	About 2 mo.	Dyspnea, chest pain, considerable weight loss. Later: became more emaciated and weaker quite rapidly	Large quantity of fluid in right pleural space. Fairly extensive fibrosis in right upper lobe. No lesions seen in left lung	Not mentioned

	AUTHOR'S DIAGNOSIS	LOCATION OF LESIONS	METASTASES	TREATMENT	RESULT
	Alveolar-cell carcinoma	All lobes, both lungs	Hilar, mediastinal and abdominal lymph nodes; liver, left kidney, adrenals, ribs and vertebrae	None recorded	Dead
	Alveolar-cell carcinoma	All lobes, both lungs	Hilar and mediastinal lymph nodes, peri- cardium, eighth left rib, liver, spleen	None recorded	Dead
1	Alveolar-cell carcinoma	All lobes, both lungs	Hilar lymph nodes of both lungs	None recorded	Dead
a	Alveolar-cell carcinoma	All lobes, both lungs	Hilar lymph nodes of both lungs, peri- cardium, sternum	None recorded	Dead
	Alveolar-cell carcinoma of lung	Right lower lobe	None	Right lower lobectomy	Recurrence 3 yr. later with involv. of remaining portion of rt. lung and chest wall. Pneumo- nectomy

TABLE II.

AUTHOR AND DATE	AGE	RACE	SEX	DURATION	SYMPTOMS	ROENTGENOGRAPHIC FINDINGS	SPUTUM
116. Fisher and Holley ^{90*} 1953	47	Y	M	Less than 3 mo.	On adm.: cough, expectoration, lower left chest pain. Later: left shoulder pain. Hospital course: progressively downhill with dyspnea, cyanosis, fever, wheezing respirations, weakness, weight loss	Innumerable stippled areas of increasing density in both lung fields. Suggested diagnosis: miliary T.B., pulmonary mycosis, and metastatic Ca (most probable)	Present but not described. Negative for TBC.
117. Fisher and Holley ^{90*} 1953	61	W	M	About 1 mo.	For 1 mo.: dyspnea, wheezing respirations, productive cough. Hospital course: became very weak and deteriorated rapidly	Diffuse mottling of both lung fields (suggestive of miliary T.B. but more probable diagnosis was pulmonary mycosis)	Present but amount not described. No hemoptysis
118. Fisher and Holley ^{90*} 1953	54	W	F	About 10 mo.	About 8½ mo. prior to adm.: "chest cold," dyspnea on exertion. About 7½ mo. prior to admission: "bronchitis." On adm.: increasing dyspnea, unproductive cough made worse by lying down	Widespread, rather fine mottling of both lung fields. Suggested diagnosis: pulmonary adenomatosis	None
119. Fisher and Holley ^{90*} 1953	62	W	M	About 3 mo.	Weakness, chest pain, wheezing and cough with scanty sputum. On admission: weight loss, slight fever. Later: weakness and dyspnea progressively worse	5 mo. prior to onset of symptoms: films during chest survey passed as within normal limits. On adm.: scattered, densely mottled infiltration throughout both lung fields; provisional diagnosis: miliary T.B. 1 mo. after adm.: bilateral extension of disease; diag. considered: fungus infection of lungs, miliary T.B., and carcinomatosis (most likely)	Scanty
120. Delarue and Graham ^{40*} 1949†	35	W	M	8-12 mo.	Chronic productive cough. Some dyspnea on exertion with palpitation and vertigo	Infiltrative process in the right lower lung field	½ cup of foul-smelling greenish-yellow sputum daily. Small hemoptysis on 1 occasion

*Case not included in the statistical analyses on which the graphs are based.

†Although not so indicated in the report of Watson and Smith⁵⁴ these cases were previously reported by Smith, Knudtson, and Watson⁶⁷ in 1949.

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CONCLUSIONS

So-called benign pulmonary adenomatosis and malignant terminal bronchiolar or alveolar-cell carcinoma are one and the same condition, varying only in their degree of malignancy in different patients or in separate portions of the same tumor. The precise site of origin has not been definitely determined. The best evidence appears to indicate that they begin in the terminal bronchioles. They clearly arise in the periphery of the lung and whether it is from the alveoli or the bronchioles is clinically unimportant. Although many authorities have expressed the opinion that this disease is of multicentric origin, no convincing evidence to substantiate that opinion could be found. On the contrary, the established facts appear to indicate that the lesion begins in a single focus from which it may spread by local extension, lymphatic or blood-borne metastases, or bronchiogenic dissemination.

There are no distinctive clinical or radiographic features by which these tumors may be definitely recognized. In general, early symptoms are minimal or absent and the late complaints are those of any widespread chronic pulmonary disease. Certain characteristics, sometimes said to be typical of this disease, such as diffuse nodular lesions involving all five lobes of the lungs and the expectoration of huge quantities of glairy mucoid sputum, are late manifestations, seen principally in patients whose prognosis is hopeless. Among the various diagnostic methods which have been employed in the recognition of these tumors, only cytologic study of the sputum and histologic examination of the excised lesion have proved to be of real value. Search of the sputum stained by the Papanicolaou method has proved most rewarding and merits widespread use in the study of patients in whom this disease may be suspected.

Excisional surgery is the only hopeful treatment. In view of the peculiar growth characteristics and manner of spread of this neoplasm, conservative pulmonary resection would seem to be the treatment of choice in a majority of patients. Surgical treatment of patients with bronchiolar carcinoma was begun so recently that sufficient time has not elapsed to permit the accumulation of a large series of patients for five-year follow-up. There are indications, however, that with early resection the five-year survival rate in this group may be better than with any other lung cancer.

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DISCUSSION

DR. H. BRODIE STEPHENS, San Francisco.—I am certain that the Association is grateful to Captain Storey for this thoughtful study of a neoplasm that he terms alveolar carcinoma. Some of you will recall that Dr. Shipman and I reported a case and termed it pulmonary alveolar adenomatosis; this neoplasm occurred in a housewife 51 years of age who had been operated upon in 1948. We reported this case at the New Orleans meeting of the Association in 1949. This patient is still alive; she has demonstrated progressive pulmonary involvement, almost complete of the right lung by a snowy infiltrate, and of approximately the lower one-half of the left lung. Malignant cells have never been seen in the sputum from this patient; many sputum studies have been done.

(Slide.) I should like to review again the peculiar appearance of this particular tumor. This is a photograph of the right lower lobe; note the waxy appearance of the lung. It looks as if gelatin had been poured down into the bronchus and allowed to solidify. The disease was not in the regional lymph nodes and seemed to be confined to the right lower lobe at the time of operation.

(Slide.) This demonstrates the patchy involvement of the lung parenchyma. Normal alveoli are seen adjacent to the adenomatous area. The columnal cells forming the tumor appear to rest upon the alveolar framework yet do not invade across it.

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DR. WILLIAM L. WATSON, New York.—We saw our first patient with so-called alveolar-cell carcinoma in 1932. Since then we have been seeing them with increasing frequency. I have one patient about whom I would like to tell you because it may add some information regarding the life history of this unusual tumor.

(Slide.) This is the film of a 65-year-old nurse in our hospital who consulted the medical service because of a cough and a slight fever in December, 1949. She received symptomatic treatment, and a routine x-ray examination of the chest was taken which showed a small area of increased density in the right lower lung field. The symptoms cleared up and she was allowed to go back to work in the operating room.

(Slide.) About two months later another roentgenogram of the chest was taken and it again revealed a mass in the right lower lung field.

(Slide.) Four months later another film was taken and showed an enlargement of the mass density.

(Slide.) Six months later another film was taken and in 1951 still another film was taken. In March, 1952, two years and four months after the original x-ray film, the patient was referred to the thoracic surgical service. Bronchoscopy was done and it was entirely negative except that we washed the bronchus out and Dr. Papanicolaou studied these washings and said it was loaded with cancer cells, probably of the alveolar-cell type. A pneumonectomy was done.

(Slide.) The bronchi from the major bronchus on down were opened and no primary tumor of bronchial origin could be elicited. The tumor, as you see, is out in the periphery, and it is a typical so-called "terminal bronchiolar or alveolar-cell carcinoma." We did a complete pneumonectomy and node dissection, and the nodes were negative.

(Slide.) We have 60 of these patients with alveolar-cell cancer and have done 34 operations; 18 pneumonectomies, 4 lobectomies, 2 segmental resections, and 10 exploratory thoracotomies. The operability rate is 57 per cent, but the resectability rate is 70 per cent.

(Slide.) Of the 18 patients having pneumonectomy, 8 are alive, 1 for five years, 2 for two years, and 5 for one year or less. With lobectomy, the number of patients alive, 4; number of patients operated on, 4; 1 alive for eight years, 2 for two years, and 1 for one year.

(Slide.) This salvage rate in the group operated upon more than five years ago shows the inaccuracy of all statistics. Here we have a 40 per cent five-year cure rate of this tumor by excisional surgery. None were cured by x-ray therapy, and none survived who had no treatment at all. In addition we have found that 21 per cent of our 60 patients did not have any symptoms prior to the time the cancer was picked up on routine chest examination.

CAPTAIN STOREY (Closing).—I wish to thank all the discussers for their interesting comments. Our experience with cytologic studies of the sputum in patients with bronchiolar carcinoma has been somewhat similar to that of Dr. Stephens. We have not had quite as good results with the Papanicolaou examination in our personal cases as Dr. Watson and his group have had at Memorial Hospital, nor have we been as successful in making a diagnosis by this means as Dr. MacDonald and his associates at the Mayo Clinic. I have personally studied many histologic sections from a large number of these lesions and I know that the picture varies considerably.

It is my opinion that whether the Papanicolaou is positive or negative is probably influenced considerably by the extent of the papillary projections within the alveoli. These are the tiny fragments of tumor which break off, are expectorated, and can be recognized histologically, not only as tumor cells, but in some cases it is possible for the pathologist to suggest the specific diagnosis of bronchiolar carcinoma when they are seen in the Papanicolaou preparation. The individual cells themselves are frequently quite benign in appearance and I believe that unless clumps of cells, as MacDonald and Woolner have described, are found, the most competent pathologist would be quite reluctant to

(Slide.) Here is the high-power photomicrograph. These cells, you will notice if you study them carefully, do not completely encircle the alveolar framework. They are columnar cells, goblet in type, secreting mucus. They appear similar to those Dr. Storey has shown today.

Our own Dr. Graham laid down certain criteria for the diagnosis of alveolar-cell carcinoma, stating that the tumor reproduced the alveolar structure of the lung. There is no evidence that such has taken place in the tumor presented by Dr. Shipman and myself. Our patient had symptoms for at least seven years prior to operation; it is now five years since operation, so our patient has had a history of about twelve years' duration. She has never demonstrated any palpable lymph node involvement, and we still cannot find abnormal cells in the sputum. So perhaps there are variants of this so-called alveolar-cell carcinoma, or perhaps there are several distinct entities.

DR. FRANK S. ASHBURN, Washington, D. C.—I too have enjoyed Captain Storey's dissertation very much. We have had experience with three cases of this condition, and I want to show the slides on one of them.

(Slide.) This is the gross specimen showing the changes similar to those described by Captain Storey, and it is very surprising in our experience to come upon such a thing.

(Slide.) The percentage of mucus in these cells is larger than in the section shown by the previous speakers. However, you will notice here a very similar arrangement and configuration of the cells, the large tombstone cells containing large amounts of mucus.

Our experience certainly corroborates Captain Storey's findings relative to the frequency and accuracy of the diagnosis of the condition by cytologic examination of either sputum or bronchial secretions. I think it well to stress that in the hands of good men this is a very helpful diagnostic tool. I am not at all satisfied with the conclusions that local excision of such lesions constitutes adequate therapy. Of course, my experience is not large enough to draw a final conclusion as to what we can do with these lesions; since Captain Storey's figures seem to me to be based largely on material of which the greater part was obtained at autopsy, I would like to ask the extent of radical excision that has to be done and ask the men with wide experience to answer that question for us if possible.

DR. GABRIEL SELEY, New York.—I agree with Captain Storey's conclusion that alveolar-cell tumors, pulmonary adenomatosis, and carcinoma of the lung are different variants of the same disease. About one year ago Dr. Touroff and I had a 45-year-old patient who presented herself because of a single nodule in the right upper lobe. There were no pulmonary symptoms. Chest roentgenograms taken two years before admission were negative. Nine months before admission during a routine examination a small nodule measuring about 3 by 2 cm. was noted in the anterior segment of the right upper lobe very similar to the one Captain Storey mentioned. Subsequent x-ray films showed a slight enlargement of this nodule and questionable cavitation. Sputum examinations were repeatedly negative for tubercle bacilli and tomograms failed to reveal any calcification.

At operation the nodule was excised by wedge resection for biopsy purposes. A frozen section was immediately reported as showing a pulmonary adenoma and a right upper lobe lobectomy was promptly performed. No nodes were noted at the hilus. The patient made an uneventful recovery and follow-up x-rays are negative for other foci. Further study of the specimen corroborated the frozen section report, and the final diagnosis was pulmonary adenoma of alveolar-cell type without evidence of malignancy. I am simply giving the pathologist's statement.

This case, then, represents a single, early, possibly benign focus of disease which, if left in, may go on to malignant changes and dissemination throughout both lungs. It is further evidence against a multicentric origin for these tumors, and I certainly feel that the minimal resection in these cases should be a lobectomy.

THE SIGNIFICANCE OF PULMONARY HYPERTENSION AS A CAUSE OF DEATH FOLLOWING PULMONARY RESECTION

WILLIAM E. ADAMS, M.D., JOHN F. PERKINS, JR., M.D. (BY INVITATION), ADOLFO FLORES, M.D. (BY INVITATION), PAUL CHAO, M.D. (BY INVITATION), AND MIGUEL CASTELLANOS, M.D. (BY INVITATION)
CHICAGO, ILL.

IN MAN, under normal conditions, the pulmonary reserve is several times that necessary to meet the requirements of the body while at rest. Evidence of this is demonstrated by the ability of patients to tolerate removal of one lung. Moreover, it is possible to withstand the resection of more than one-half of both lungs when this is performed in stages. In dogs, the reduction of lung capacity to as little as one upper lobe (approximately 15 per cent of the total lung volume) may be successfully accomplished by bronchial stenosis, when produced in stages over a period of several months.¹

In patients with bilateral alteration of the lung due to inflammatory, degenerative, or other conditions, the pulmonary capacity may be considerably reduced. This is especially true in the so-called older age group. In non-malignant disease it is possible to limit pulmonary resection, thus preserving maximum lung function. However, in the case of malignant lesions, it has been generally believed that removal of the entire lung along with adjacent tumor-bearing tissue is the operation of choice when it can be tolerated by the patient.² Since the risk of pneumonectomy is increased in the older age group having poor pulmonary reserve, repeated attempts have been made to determine the "resection tolerance" of such patients prior to operation. Studies made by a number of investigators have increased our knowledge of factors concerned with this problem. Recently, special attention has been given to the problem of changes in pulmonary tension attending the resection of lung tissue both in animals and in man.³⁻⁶ Cardiac catheterization, although practiced for some time, has been made much more practical in recent years and has contributed much to these investigations. Most of the publications dealing with this problem have been concerned with patients in whom pulmonary resection was made for various conditions. There has therefore been little opportunity to study the alterations in cardiopulmonary function attending lung resection where maximal "resection tolerance" has been reached.

The present report deals chiefly with experiments in which pulmonary resection was carried out to the limit of tolerance without loss of the animal. The experiments were designed to determine the role played by the vascular element (perfusion) versus the pulmonary element (diffusion) of the lung as a significant factor in the cause of death after pulmonary resection and also to investigate the various factors which influence pulmonary tension.

From the Departments of Surgery and Physiology of the University of Chicago.

This work was supported in part by United States Public Health Grant No. RG1254(C) and in part by the Douglas Smith Foundation for Medical Research of the University of Chicago.

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make the diagnosis of pulmonary malignancy in this group of patients. The isolated cells are usually of uniform size and shape, their nuclei are normal and the nuclear-cytoplasmic ratio is also commonly normal.

I am pleased to hear Dr. Ashburn's comments. I do not pretend to have had sufficient experience to provide a categorical answer to the question as to the extent of excisional surgery which is indicated in the treatment of this disease. However, I have been able to find in the literature reports of 218 cases of bronchiolar carcinoma, including those which we are reporting, and have personally reviewed each of the original case reports. A statistical analysis of those cases will appear in the published manuscript. Of particular interest are the figures relative to metastases in these lesions. Among the reported cases, metastases occurred in roughly 50 per cent of the cases; 54 per cent is the precise figure, I believe. Among those patients who have metastases, mediastinal involvement alone was present in only one-third; one-third showed both local and distant metastases, and the remaining one-third showed distant spread only. These figures make it seem rather illogical to me to perform surgery of a radical nature unless the local conditions found at operation so dictate. Obviously, if one finds mediastinal nodes, proved to be malignant on frozen section examination, or even enlarged firm nodes which would arouse a suspicion of carcinoma by their gross appearance, more radical operation would be indicated.

In spite of what is said in the published abstract of my paper, and even though I do have one patient whom I treated by segmental resection who is alive and without evidence of disease nineteen months following operation, I have come to agree with Dr. Seley's comment that a lobectomy should probably be the minimum operation in patients with this disease. I personally do not intend to treat any future patients who have this tumor by segmental resection. In reviewing many histologic sections from these lesions I have seen tumor cells in the pulmonary lymphatics, both subpleural and perivascular, too frequently to make me feel comfortable in undertaking a really small localized operation for this neoplasm.

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In earlier communications^{7, 8} it was shown that a rise in pulmonary artery tension could be expected in dogs after the removal of one lung. The average elevation in tension in a group of thirty dogs was from an original of $32/5$ to $44/5$ mm. Hg following operation. This increase in pulmonary tension was maintained for at least several months. In a second group of thirteen dogs where pulmonary resection was extended in stages to include the entire lung with the exception of one upper lobe, the pulmonary tension increased from an original average of $40/5$ to an average of $64/8$ mm. Hg following surgery. Thus the pulmonary artery pressure was doubled ($32/5$ to $64/8$). Some of these animals died of spontaneous pneumothorax or of infection; however, most of them at autopsy demonstrated evidence of cardiac failure, a bloody, frothy material in the tracheobronchial tree and edema of the lungs being found. Four of the animals survived this extensive pulmonary resection.

An attempt was made to increase the survival rate by the use of a plastic sponge prosthesis in the pleural space following the initial operation which was a total pneumonectomy. This procedure failed completely since the elevation in pulmonary artery pressure was even greater in these animals following the second operation. None of this group of ten dogs survived.

EXPERIMENTAL METHODS

Ten healthy mongrel dogs weighing from 10 to 15 kilograms were used. A total right or left pneumonectomy had been made six to twelve months prior to the studies now being reported. Anesthesia for the final operation consisted of intravenous pentobarbital sodium 30 to 35 mg. per kilogram with intratracheal positive pressure oxygen, or ether-oxygen without the barbiturate. Prior to operation on the chest a No. 8F cardiac catheter was introduced under fluoroscopic control into a pulmonary artery via an external jugular vein. Heparin (0.5 mg. per cubic centimeter of saline) was used to maintain a patent catheter. In earlier experiments, pressures were measured with a Hamilton manometer or with a Sanborn electromanometer. In the present study, mean pressures only were measured by means of a saline manometer. Anesthetic agents and oxygen mixtures were administered through an intratracheal catheter under positive pressure or through a tracheotomy tube.

Continuous recording of arterial blood oxygen saturation was made by means of an oximeter cuvette inserted between a carotid artery and an external jugular vein and connected to a recording oximeter designed by one of us (J. F. P.) and constructed in the physiology laboratory.⁹ Heparin, 5.0 mg. per kilogram, intravenously, and 5.0 mg. per kilogram, intramuscularly, was used to prevent clotting when the cuvette was connected.

The chest was opened through the fifth interspace and an occlusion unit was placed around the pulmonary artery immediately below the branches to the left or right upper lobe. Thus, occlusion of the vessel at this point would reduce the total pulmonary function to one upper lobe or approximately 15 per cent of normal. In some animals a second occlusion unit was placed around the bronchus at the same level. The occlusion units consisted of a loop of heavy braided silk passed around the artery or bronchus, then introduced into a

polyethylene tube, and both brought out through a small puncture wound in the chest wall. These tubes were filled with petroleum jelly and also clamped to avoid a pneumothorax. A small rubber catheter for maintaining expansion of the lung was also brought out through a puncture wound.

In order to demonstrate more striking changes in pulmonary tension or arterial oxygen saturation when the pulmonary capacity was suddenly reduced to a maximum tolerance level, an apparatus for exercising the animal was constructed and connected to all four extremities. Exercise consisted of intermittent (60 per minute) electrically stimulated contractions of the shoulder girdle and the thigh muscles. A moderate to vigorous degree of exercise was used.

Employing this described arrangement, changes in pulmonary artery tension and arterial blood oxygen saturation were determined under the following conditions:

- A. Dog at rest breathing air.
- B. Dog at rest breathing air with lung capacity reduced to 15 per cent.
- C. Dog at rest breathing oxygen (100 per cent).
- D. Dog at rest breathing oxygen (100 per cent) with lung capacity reduced to 15 per cent.
- E. Dog exercising while breathing air.
- F. Dog exercising while breathing air with lung capacity reduced to 15 per cent.
- G. Dog exercising while breathing oxygen (100 per cent).
- H. Dog exercising while breathing oxygen (100 per cent) with lung capacity reduced to 15 per cent.

RESULTS

A. With the Animal at Rest and Breathing Air.—Both pulmonary artery pressure and blood oxygen saturation varied considerably with the depth of anesthesia and with the degree of activity of the animal. Oxygen saturation varied from 66 to 90 per cent. The usual saturation was 89.5 per cent. Pulmonary artery pressure varied from 20.5 to 43.0 cm. saline.

C. With the Animal at Rest and Breathing 100 Per Cent Oxygen.—The pulmonary artery tension was the same as in A while breathing air. However, the blood oxygen saturation was elevated to as high as 100 per cent in some animals. The usual level for the group was 97.8 per cent.

B and D. With the Animal at Rest Breathing Air or Oxygen and With Lung Capacity Reduced to 15 Per Cent of Normal.—The effect on pulmonary artery tension was similar during both conditions. Under deep narcosis (with pentobarbital sodium) the increase in tension was as low as 4.5 cm. saline. The highest elevation was 35.5 cm. saline or 118.0 per cent of the original value. The usual elevation for the group was 31.2 cm. or 90.7 per cent.

Blood oxygen saturation was reduced very little when compared with the marked change in pulmonary tension. While breathing air the saturation fell from 3 to 6 per cent, or an average of 4.5 per cent when lung capacity was lowered to one lobe. While breathing oxygen no reduction in saturation was observed in some animals. The average fall for the group was 3.8 per cent.

E and F. Influence of Exercise Before and After Reducing Lung Capacity to 15 Per Cent While Breathing Air.—The effect of work on pulmonary artery tension in most animals was dramatic whether breathing air or 100 per cent oxygen. There was a rapid increase in tension averaging 14.7 cm. saline or 60 per cent, with one-half of the lung functioning, and 20 cm. saline or 80 per cent increase in tension after reduction to only one lobe. Thus when the effect of exercise was added to the effect of reduction of capacity from one lung down to one lobe, the pulmonary tension was elevated over 200 per cent in some animals.

Blood oxygen saturation remained unchanged in two dogs, while in the remainder there was as much as an 18 per cent fall, with an average of 8 per cent decrease, before reduction of lung capacity. The oxygen saturation fell as much as 19 to 50 per cent, with an average of 29.6 per cent, when only one lobe was functioning.

When breathing 100 per cent oxygen, blood saturation was little affected by exercise, irrespective of whether lung capacity was 50 or 15 per cent of normal. Pulmonary artery pressures, however, were altered by exercise in amounts similar to those occurring when the animals were breathing air.

DISCUSSION

Figs. 1 and 2 (Dog 36) show systolic and diastolic right ventricular pressure curves during a right pneumonectomy and subsequently during a left lower lobectomy. The systolic pressure during right pneumonectomy became elevated by approximately 30 per cent. This elevation persisted during the several months intervening between the two stages. At the end of the second stage the systolic pressure was elevated approximately 75 per cent over that at the beginning of this procedure. However, this (80 mm. Hg) was more than 150 per cent above the level at the beginning of the first operation (30 mm. Hg). The curves shown on this dog were quite characteristic of the group reported in a former communication.⁷

As noted previously, while at rest and breathing air the pulmonary tension in most animals became elevated by as much as 90 per cent when lung capacity was reduced. In some animals it was increased over 100 per cent. At the same time the saturation in arterial blood oxygen was decreased by a relatively small amount, an average of 4.5 per cent. When 100 per cent oxygen was added to the inhaled mixture this decrease in saturation was minimal, or the level remained the same as that prior to reduction of lung capacity to 15 per cent. Fig. 3 (Dog 737) illustrates these points. Oxygen saturation was decreased approximately 5 per cent (88 to 83) when the lung capacity was reduced to one lobe. The right ventricular pressure, however, rose from 53 to 82 cm. of saline, representing an elevation of over 50 per cent.

Fig. 4 (Dog 737) illustrates the effect of oxygen and of exercise. While breathing 100 per cent oxygen there was no change in the level of blood oxygen saturation when the lung capacity was reduced. Likewise, when exercise was begun the saturation continued at a level of 100 per cent. On changing from

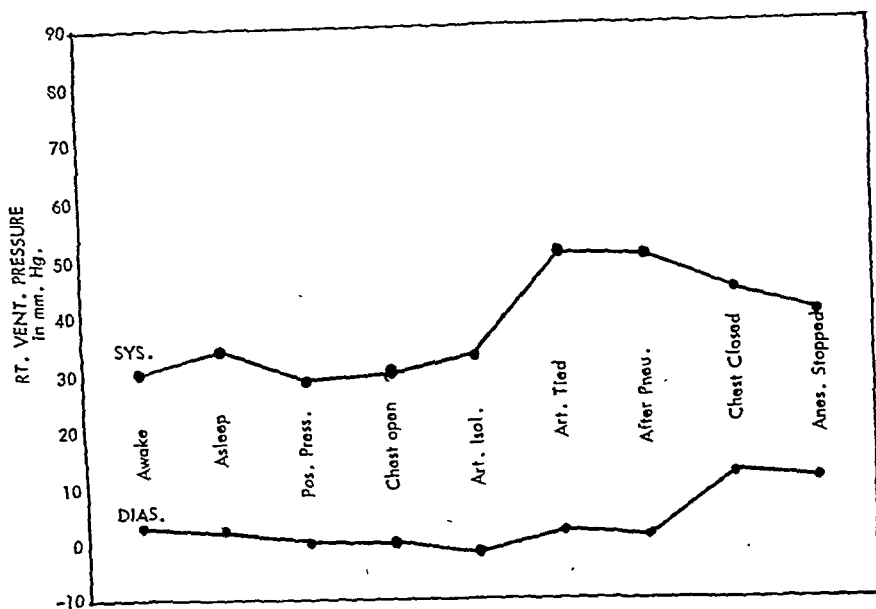


Fig. 1.—Dog 36. Shows systolic and diastolic right ventricular pressures during a right pneumonectomy. Note that the systolic pressure was elevated by approximately 30 per cent following the operation.

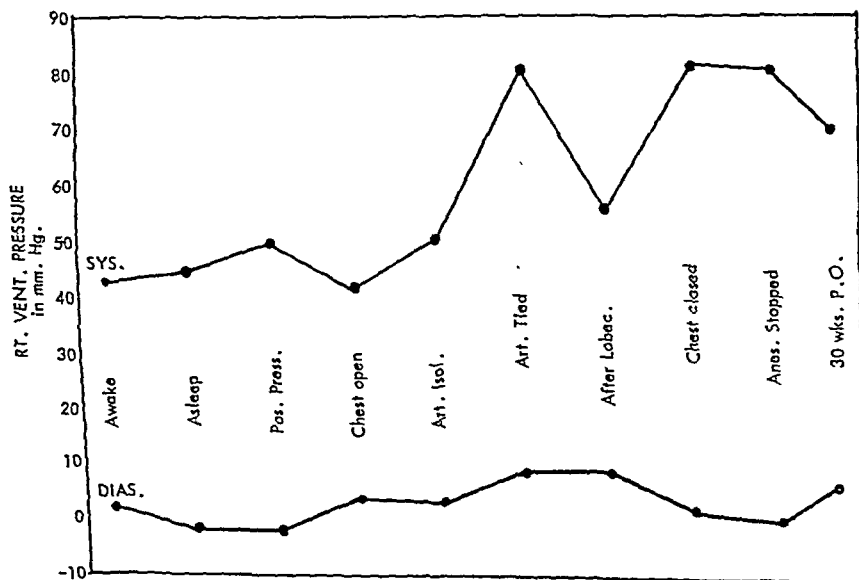
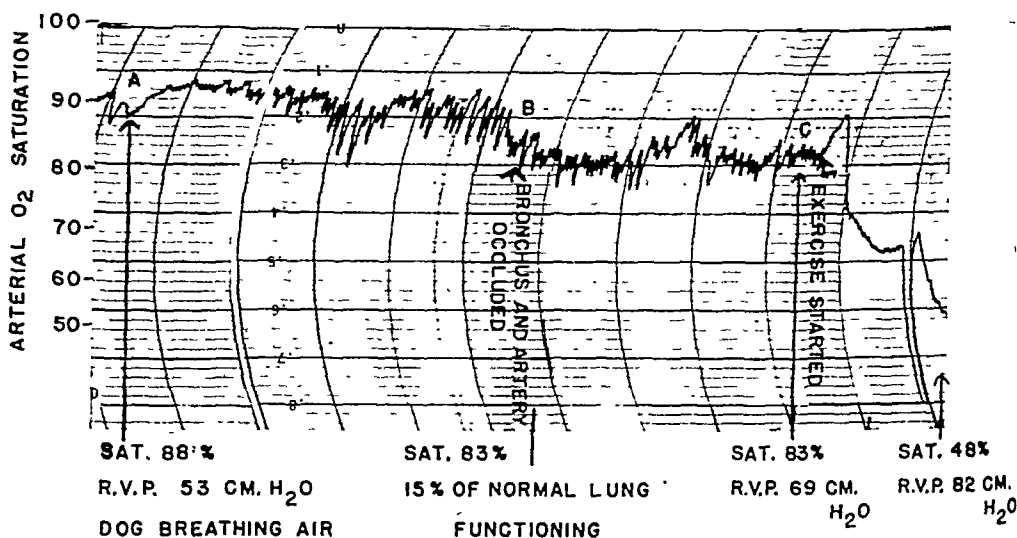


Fig. 2.—Dog 36. Shows systolic and diastolic right ventricular pressures during resection of the left lower lung lobe in a dog whose right lung had been resected six months previously. Note elevation of systolic pressure to a level of 80 mm. Hg. which was 150 per cent above the level of pressure at the beginning of the first operation (30 mm. Hg.).

100 per cent oxygen to air the saturation immediately fell dramatically to a level of 63 per cent and continued on downward in three minutes to 45 per cent. Release of the occlusion units restoring the lung capacity to 50 per cent produced a rise in oxygen saturation from 45 to 63 per cent. The right ventricular pressure in this animal had risen from an original level of 35 cm. saline to 96 cm. of saline after reduction of lung capacity combined with exercise. This represented an elevation of two and three-fourths times the original level, or 275 per cent.

BLOOD O₂ SATURATION AND RT. VENT. PRESSURE IN REDUCED PULMONARY CAPACITY



DOG # 737 - 3/25/52

Fig. 3.—Dog 737. Shows a marked elevation in right ventricular pressure with reduction in lung capacity and exercise of the animal. Oxygen saturation was reduced by only 5 per cent when lung capacity was reduced to one upper lobe. The effect of exercise on oxygen saturation is demonstrated.

Fig. 5 (Dog 469) illustrates a fairly characteristic curve of blood oxygen saturation and pulmonary artery pressure during the various conditions studied in the experiment. There was a marked increase in pulmonary artery pressures on reduction of lung function in most instances with relatively little reduction in blood oxygen saturation until exercise was begun. Thereafter a greater amount of oxygen was required by the animal.

Fig. 6 (Dog 28) illustrates the effect of reduced lung capacity while receiving 100 per cent oxygen before and during exercise, and later while breathing air. There was no change in blood oxygen saturation as a result of either reduction of lung capacity or exercise while breathing oxygen. Pulmonary artery tension, however, increased from 48.5 to 68.5, an increase of almost 41

per cent. The blood oxygen saturation was lowered 7 per cent by reduction in lung capacity and 10 per cent by exercise, when the dog was breathing air.

Fig. 7 (Dog 469) illustrates the effect of exercise, inhalation of oxygen, and reduction of lung capacity on arterial blood oxygen saturation and right ventricular pressures. Exercise produced relatively little effect on blood oxygen saturation while the animal was breathing air before lung capacity had been reduced. Following reduction of lung capacity there was an immediate fall in saturation, from 85 to 55 per cent. On breathing 100 per cent oxygen the saturation immediately rose to 97 per cent within a period of less than a minute. During this time the right ventricular pressure became elevated from 20 to 50 cm. of water, an increase of 150 per cent.

BLOOD O₂ SATURATION AND RT. VENT. PRESSURE IN REDUCED PULMONARY CAPACITY

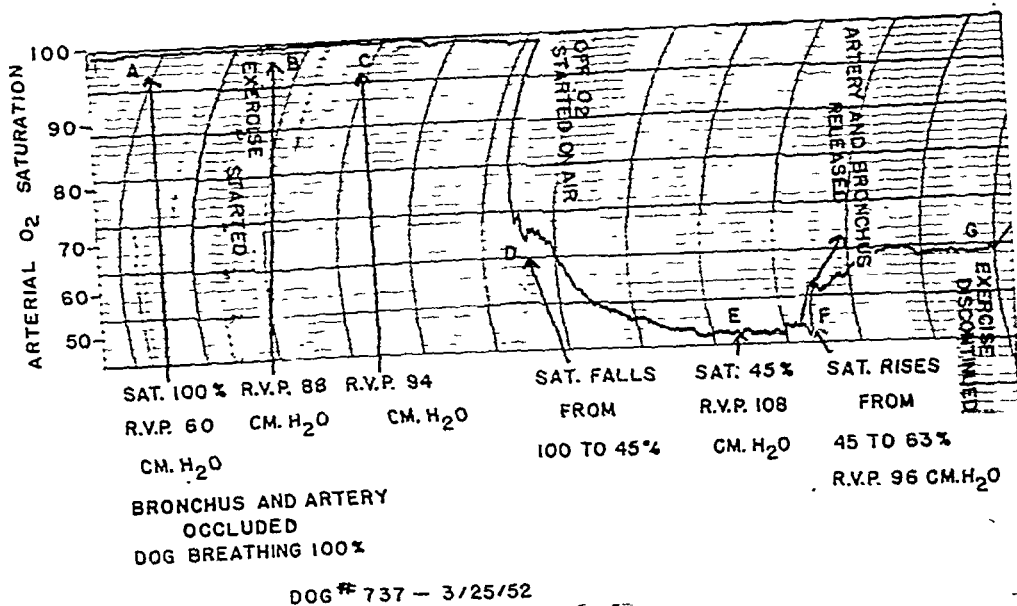


Fig 4—Dog. 737. Shows a complete lack of effect on blood oxygen saturation by either reduction of lung capacity to one lobe or on exercising the animal. The right ventricular pressure on the other hand became elevated 50 per cent. On breathing air there was a precipitant fall in oxygen saturation which did not return to the previous level when the capacity was returned from 15 to 50 per cent of normal.

The results of these experiments in conjunction with those reported in previous communications lend strong support to the belief that elevated pulmonary tension may be a significant factor in the cause of death following lung resection in patients with markedly reduced pulmonary reserve. The amount of reduction in lung capacity necessary to produce in dogs a serious level of pulmonary hypertension was found to be 80 to 85 per cent. In most animals this has been accompanied by an increase of 75 to 100 per cent in pulmonary artery pressure. Despite this fact, the accompanying decrease in blood oxygen

saturation has been relatively small, an average of only 4.5 per cent. These results support the view that the lung in a reduced reserve state, but without the presence of a physiologic arteriovenous shunt, may be able to adequately oxygenate the blood, but that the accompanying pulmonary hypertension may reach a critical level. In patients with some degree of pulmonary hypertension due to bilateral disease, a much greater pulmonary tension may follow the resection of one lung. Furthermore, such factors as anoxia and emotional strain may in themselves contribute to elevation in pulmonary tension as shown by Motley and his associates,¹⁰ Duke and Killick,¹² and Cargill and Hickam.¹¹

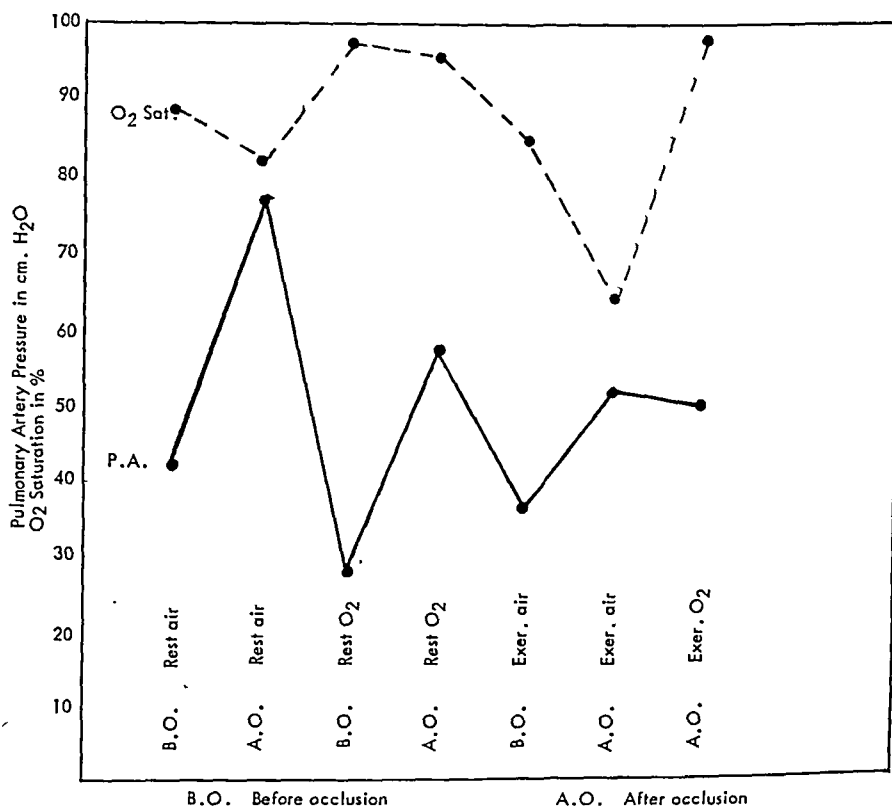


Fig. 5.—Dog 469. Illustrates a fairly characteristic curve of blood oxygen saturation and pulmonary artery pressure during the various conditions studied in the experiment. Note a marked increase in pulmonary artery pressure on reduction of lung capacity to 15 per cent (*I* upper lung lobe) with relatively little fall in oxygen saturation.

In animal experiments deep narcosis with pentobarbital sodium markedly lowered both blood oxygen saturation and pulmonary tension, whereas light ether anesthesia and muscular activity of the animal during induction produced an elevation in pulmonary tension.

Since anoxia may play a major role in the elevation of pulmonary tension, it may be an additional factor of importance both during anesthetic induction accompanied by respiratory depression or spasm as well as during the course of operation if oxygenation is not constantly maintained at an adequate level.

It is also well known that either collapse of the lung or overdistension of the lung impedes the flow of blood through the lesser circulation, thus tending toward increase in pulmonary tension. In patients with low pulmonary reserve it is imperative that optimum inflation of the lung be maintained while the chest is open. Following operation, retention of bronchial secretions, accompanied by atelectasis and pneumonitis, or by a physiologic shunt, increases the hazards from anoxia and pulmonary hypertension.

BLOOD O₂ SATURATION AND PUL. ART. PRESSURE IN REDUCED PULMONARY CAPACITY

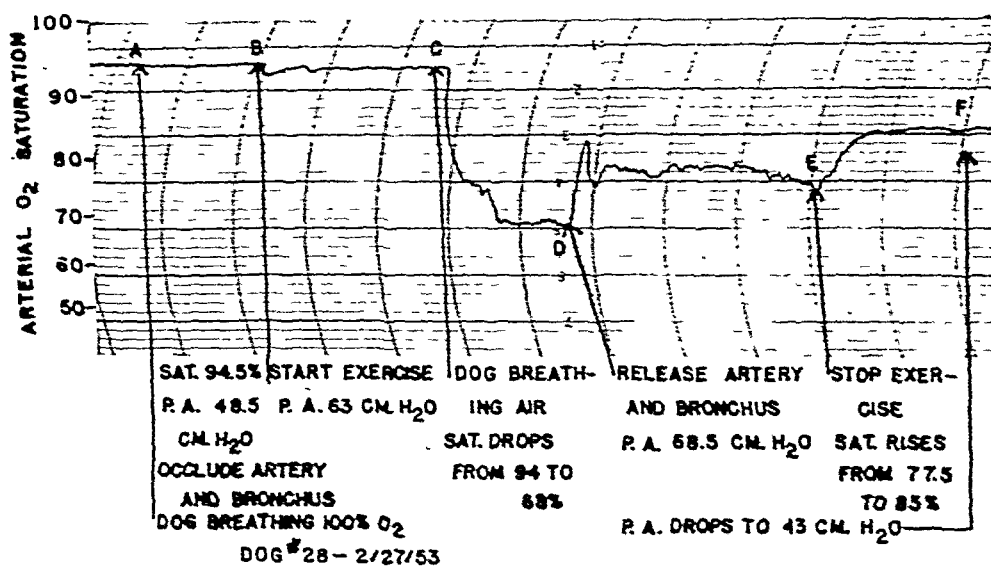


Fig. 6.—Dog 28. Note the lack of change in blood oxygen saturation as a result of reduction in capacity or as a result of exercise while breathing oxygen. The pulmonary artery tension however increased from 48 to 68 cm. of saline. On breathing air the saturation dropped markedly and did not recover on increase of lung capacity and cessation of exercise.

Resection of a lung containing anatomic or physiologic arteriovenous fistulas (shunts) may also cause an elevation of pulmonary tension as illustrated by a patient in Fig. 8. The tension was increased with closure of each arteriovenous shunt. In spite of the fact that this patient previously had a pneumonectomy on the opposite side for the same lesion, his original pressure in the right ventricle after induction of anesthesia was complete, was only 25/10 mm. of mercury. At the conclusion of the operation the pressures were 45/0 mm. of mercury. Thus, with the closure of three arteriovenous fistulas the systolic pressure was elevated 80 per cent.

Our findings (Table I) and those of others³ would indicate that severe pulmonary hypertension occurs infrequently. However, most studies on human beings have been made with the patient at rest and have not included a number

TABLE 1. PULMONARY ARTERY PRESSURES* BEFORE AND FOLLOWING OCCLUSION OF THIS VESSEL IN PULMONARY RESECTION

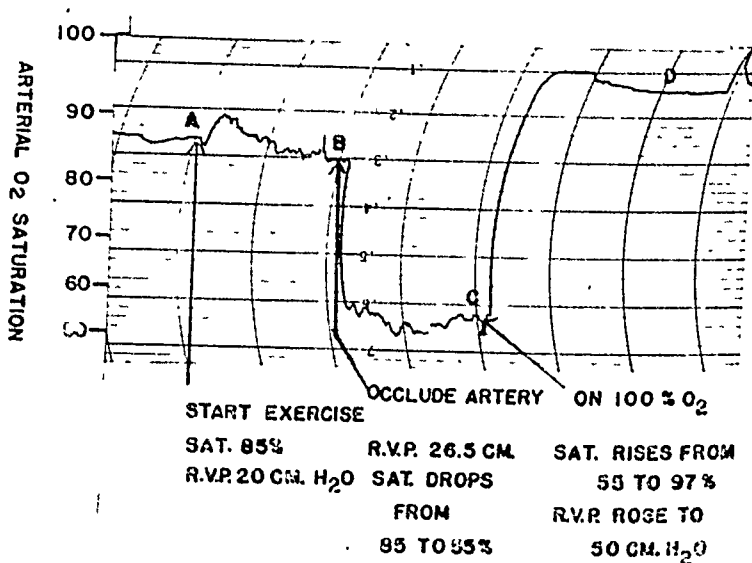
PATIENT	AGE	SEX	DIAGNOSIS AND OPERATION	PRESSURE IN CM. SALINE	
				BEFORE OCC.	AFTER OCC.
1. E. W.	23	M	Bronchial adenoma—pneumonectomy	38.5	38.5
2. P. G.	71	M	Carcinoma and tuberculosis—pneumonectomy	35.0	13.0
3. L. R.	51	M	Carcinoma—pneumonectomy	21.6	21.6
4. G. D.	53	M	Cavitary silicosis—pneumonectomy	12.0	53.0
5. T. C.	67	M	Carcinoma—lobectomy	31.0	37.0
6. J. V.	45	M	Lung abscess—pneumonectomy	22.5	28.5
7. L. G.	41	F	Bronchiectasis—bilateral resection	10/21.5	70/50†
8. R. R.†	31	M	Multiple A-V fistula—pneumonectomy, 1913 (small resections of right upper, middle, and lower lobes)	27.5/10 B.P.: 100/60	15/0† 90/60

*Pressures recorded except in 7 and 8.

†Catheter became dislodged into right ventricle.

‡Pressures in mm. Hg.

BLOOD O₂ SATURATION AND RT. VENT. PRESSURE IN REDUCED PULMONARY CAPACITY



DOG #469—2/23/53

Fig 7.—Dog 169. Exercise altered the blood oxygen saturation but little while the animal was breathing air. Exercise plus reduction of capacity produced a sudden drop in saturation which immediately recovered on changing from inhalation of air to 100 per cent oxygen. The right ventricular pressure increased from 20 to 50 cm. of saline or 150 per cent, with reduction of capacity and exercise.

of factors during the early postoperative course which may influence considerably the level of pulmonary tension. When pulmonary hypertension does develop it may very well be the most significant factor in the outcome of some patients following pulmonary resection. Measurement of pulmonary tension at operation may provide information for guidance of the management both during and following surgery.

SUMMARY AND CONCLUSIONS

1. Pulmonary hypertension of serious import may be produced in dogs by resection of 80 to 85 per cent of the lung.
2. The accompanying fall in blood oxygen saturation is small (average 4.5 per cent) in view of the severity of the pulmonary hypertension.

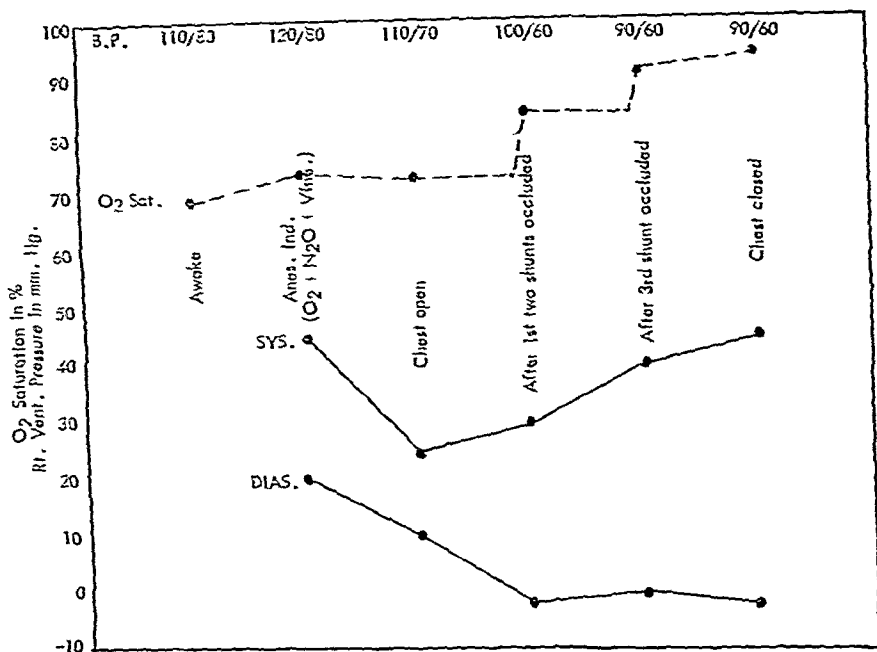


Fig. 8.—P. R. No. 241255. Closure of A-V fistulas of the lung. Correlation of right ventricular pressures with arterial blood oxygen saturation and systemic arterial pressures in a patient during the closure of three arteriovenous fistulas of the right lung. The left lung had previously been removed for the same type of lesion.

3. When a demand for more oxygen was produced through exercise, a more severe grade of pulmonary hypertension as well as a much greater reduction in blood oxygen saturation developed.

4. Inhalation of 100 per cent oxygen restored to a normal level the lowered blood oxygen saturation produced by exercise and reduced lung capacity but did not alter the severity of the degree of pulmonary hypertension.

5. Determination of pulmonary tension at operation may aid in both operative and postoperative management.

We wish to thank Mr. Willard Webber for technical assistance.

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DISCUSSION

DR. AARON HIMMELSTEIN, New York.—We have been interested in the problems of pulmonary hypertension in Dr. Cournand's laboratory for some time. I think that in speaking of pulmonary hypertension we should remember two things—that is, that pressure varies with flow and varies with resistance. In Dr. Adams' experiments he is trying, I believe, to define the maximum of pulmonary tissue that one can leave after resection and produce hypertension at rest.

We have measured the flow in patients who had a pneumonectomy. At rest, when the flow is presumably minimal no hypertension was found. When these patients are exercised it was regularly demonstrated that hypertension developed as flow increased. The ability of a normal pulmonary vascular bed to absorb an increase in flow without a rise in pressure apparently extends to about a threefold increase in flow, which in the normal is never reached. However, when a patient has a pneumonectomy all the flow is immediately doubled through the remaining pulmonary artery, and mild exercise raises the flow above a threefold increase and causes hypertension.

We have been interested too in whether bilateral resections of the amount of pulmonary tissue that is comparable to a pneumonectomy, in which the pulmonary vascular bed in distended lung occupying both chests has the same effect as does pneumonectomy. In Captain Storey's department at St. Albans Naval Hospital I am familiar with the pursuit of this information, and the results are essentially similar to those found in the group of pneumonectomies that we studied.

DR. ADAMS (Closing).—It is, of course, realized that in animals we are able to control the nature of the lung better than is possible in a human being, and in problems dealing with inflammatory or degenerative disease we have a combination of factors playing a role. As Dr. Himmelstein has pointed out, we have cut down the lesser circulation until elevation in pressure resulted. However, it seems to me that unless we have a physiologic shunt operating, and we frequently do in human beings, the effect of reduced pulmonary capacity on blood oxygen saturation is not going to be as detrimental as is the effect on pulmonary artery pressure. As was indicated this morning, we are constantly faced with problems dealing with markedly lowered pulmonary reserve. If we can get information that will give us the true status of both the vascular and the pulmonary factors, we can then do a much better job for our patients.

PREVENTION OF CHEST WALL DEFECTS: USE OF TANTALUM AND STEEL MESH

DONALD B. EFFLER, M.D.
CLEVELAND, OHIO

SURGICAL removal of a malignant chest wall tumor is best accomplished by radical block excision allowing a wide margin of normal tissue on all sides of the resected specimen. Failure to provide an adequate tissue margin will enhance the prospect of local recurrence and decrease the possibility of cure.

The principle of block excision has been applied to the chest wall for years;¹⁻³ successful removal of large segments of the bony thorax and related soft parts is no longer a momentous undertaking when adequate supportive measures are available.

Defects of the chest wall following surgery or trauma may pose a serious problem. To cure the patient of malignant disease, it has been necessary to disregard the resultant chest wall deformity; nevertheless, the creation of an extensive defect has been a deterrent and too often has resulted in a compromise operation.

Frequently, the surgeon has observed that the patient tolerated the definitive operation much better than the resultant postoperative defect.

In addition to an unsightly deformity, there may be serious disturbances of respiratory physiology. An unsupported chest wall is associated with paradoxical respiration which may incapacitate the patient who has low pulmonary reserve. Improper ventilation of the affected pulmonary tissue is manifested by an increase in the pulse and the respiratory rate, particularly in the older patient. This has been attributed to a localized accumulation of alveolar carbon dioxide in that portion of the lung hampered by paradoxical respiration. The cough reflex is also impaired, further compromising the respiratory system.

Surgical treatment of chest wall defects has been described in the literature for many years. Methods of correction have been proposed by Maier,² Maurer and Blades,³ Watson and James,⁴ and others. Most of these methods are applicable as secondary procedures and involve the use of rib struts, fascial grafts, and dermal transplants. Invariably the authors emphasize the utilization of the patient's own tissues in bridging the defect. Each method has individual merits and disadvantages, and none is adaptable to all situations. In most cases the procedures are applicable as corrective operations after the defects have been established. In addition, the technical aspects are by no means simple, and in some instances considerable caution must be used lest a bad situation be aggravated.

From the Cleveland Clinic and The Frank E. Bunts Educational Institute.
Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 29, 1953.

Attempts to bridge defects with foreign substances have been reported by many authors, though generally these adjuncts have been unsuccessful when applied to the chest wall. Plates of silver, steel, plastics, and Vitallium have been utilized in defects of skull and long bones, but they have proved



A.

B.



C

Fig 1—1, Primary carcinoma of the breast with invasion and fixation of the underlying chest wall. No distant metastases or lymphatic extension were demonstrated. B, Appearance following conventional radical mastectomy with block excision of the anterior chest wall. Tantalum mesh was employed and covered by the thin skin flap. C, Radiographic appearance of the thorax after mastectomy and reconstruction with tantalum mesh.

ineffective when used in the chest. In all probability the constant motion associated with the mechanics of respiration, has been the chief factor responsible for the failures when fixed plates are used. It seems unlikely that a plate, regardless of the substance used and its lack of tissue reaction, could become an integral part of the supporting tissues of the chest wall. By its very nature, a smooth plate resists intimacy with surrounding muscle and fibrous tissue; when these structures are subject to constant changes in stress and strain, the possibility of union becomes more remote.

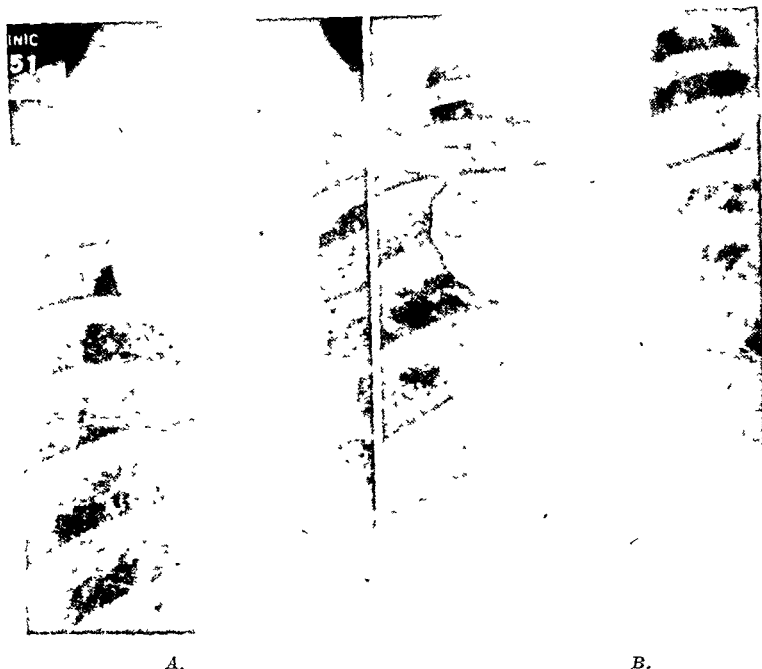


Fig. 2.—*A*, Roentgenogram demonstrating a large, metastatic, thyroid carcinoma involving the manubrium. A radical thyroidectomy had been performed approximately two years prior to the appearance of this metastasis. *B*, Radiographic appearance of the chest following resection of upper one-half of the sternum and reconstruction with steel mesh. The inner thirds of both clavicles have been removed.

Blades^{3, 5} has repeatedly emphasized the hazards in using metal plates to repair traumatic chest wall defects. Griswold⁶ and Campbell⁷ each report a case where tantalum plates were employed following resections of the manubrium and body of the sternum; in Griswold's case the plate was subsequently removed because of secondary hemorrhages. Campbell expresses the belief that a tantalum plate used for permanent prosthesis would have better chance for success as substitution for the upper half of the sternum than for the lower half. Beardsley⁸ used tantalum plates in three cases where large operative defects of the chest wall were created; in each case it was necessary to remove the prosthesis at a later time because of suppuration, presumably due to foreign body reactions. Paulson⁹ abandoned the use of tantalum plates on

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the chest wall; five patients in this group required corrective surgery for defects produced by trauma or inflammatory disease. In addition to the twenty-one patients mentioned, mesh has been used on five occasions in the treatment of large diaphragmatic hernias and in one instance for the surgical correction of eventration of the diaphragm. Our experience with these patients during the past four and one-half years and our observations are subsequently reported.

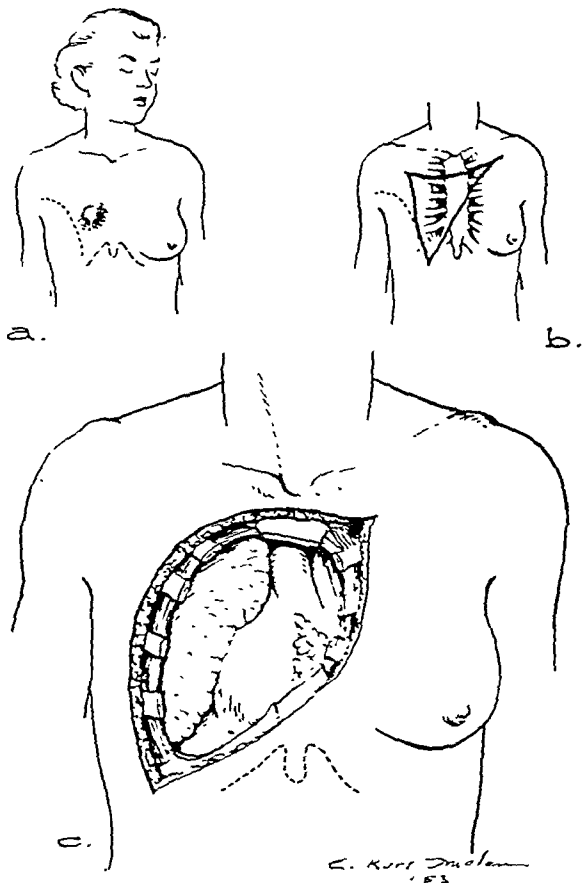


Fig. 4.—This drawing demonstrates the principle of block excision for a malignant neoplasm of the anterior chest wall. *a*, The illustration is taken from a case of recurrent carcinoma of the breast appearing four years after radical mastectomy. *b*, The heavy lines demonstrate the triangular block excised from the anterior chest wall. *c*, The excision includes sternum, ribs, and supporting soft parts. Underlying pleura and mediastinal fascia were included. The pericardium is intact.

TECHNIQUE

Radical excision of the chest wall lesion is carried out under endotracheal anesthesia. Supporting structures of the thorax and upper abdomen are sacrificed without regard for the subsequent closure in order to provide an adequate tissue margin around the neoplasm. Confidence in mesh prostheses has relieved the fear of creating an intolerable defect and thereby improved the caliber of this type of cancer surgery.

chest wall defects, attributing failure to the constant motion of the thorax. We are able to find only one report where satisfactory results were obtained and the plate retained its original position.⁷

In 1948, Koontz¹⁰ reported his clinical and experimental results in the use of tantalum mesh to repair ventral hernias. In contrast to a plate, the mesh presents a flimsy screen which is easily cut to desired shape and size. Upon first consideration it does not appear durable nor capable of offering support against mechanical stress, and yet it must be remembered that the principle of the mesh is entirely different from that of the plate. The mesh offers a lattice of nonreactive material which is incorporated rapidly by fibroblasts. The resultant proliferation produces an interwoven, fibrous mass with the lattice acting as the skeleton structure; this differs fundamentally from the encapsulation produced around a flat sheet or cap of metal. As Koontz^{10, 11} has shown so conclusively in his experiments, the mesh becomes an integral part of the abdominal wall rather than a tolerated foreign body.



Fig. 3.—*A*, A large recurrent chondrosarcoma of the chest wall and upper abdominal wall. The incision of the previous operation is clearly visible. Whereas the tumor mass was of considerable size, there was no evidence of distant metastases or extension of the neoplasm through the pleura or peritoneum. The large mass was resected by block excision of the chest wall, diaphragm, and upper abdominal wall; the resected portion of the thoracic cage contained portions of seven ribs. *B*, Appearance of the patient approximately nine months after surgery. Stainless steel employed to reconstruct the chest wall, diaphragm, and upper abdominal wall has given a very satisfactory surgical result. The right breast has been used as a skin flap in an effort to close the original defect; the scar to the right of the midline is that of the releasing incision and skin graft employed at the time of closure.

Mesh prostheses have been employed in twenty-one patients who were operated upon for lesions of the thoracic cage at the Cleveland Clinic. The majority of these patients were treated for primary or metastatic neoplasm of



Fig. 5.—*A*, Roentgenogram demonstrating tantalum mesh employed in the reconstruction of the anterior chest wall. This film made about six weeks after operation. *B*, Fourteen months after operation there has been appreciable breakdown of the tantalum mesh. It is my opinion that this is due to fatigability of tantalum mesh and accounts for its inability to tolerate continuous shearing stress.

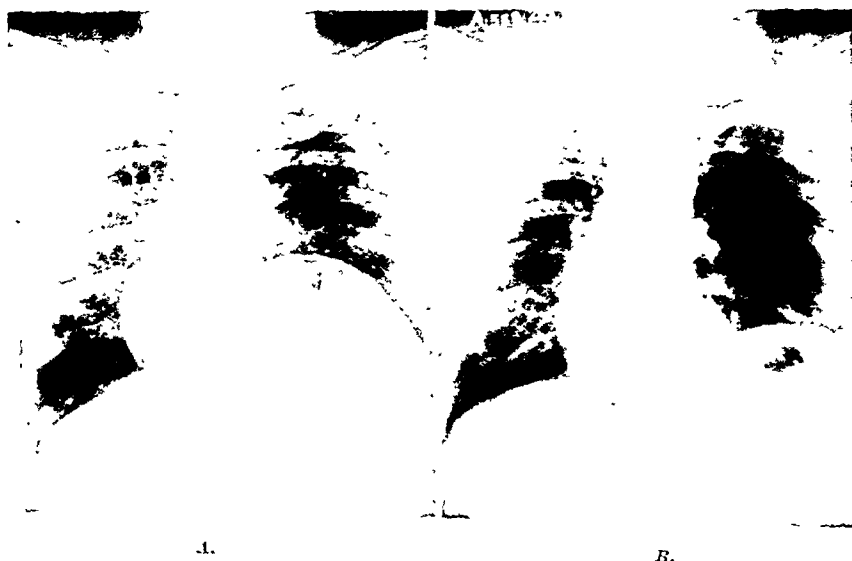


Fig. 6.—*A*, Roentgenogram demonstrating eventration of left diaphragm. *B*, Radiographic appearance approximately eighteen months after correction and reinforcement with radio-stainless steel mesh.

Following the block excision and necessary hemostasis, the defect is measured for the mesh prosthesis. The technical aspects of placing mesh are simple. The defect is overlapped by a single or double thickness of mesh which is cut to approximate size; and the edges are turned in to prevent fraying and to provide a more secure border for holding the suture material. Direct contact between mesh and underlying lung, diaphragm, or abdominal viscera may occur without apparent untoward reaction. The prosthesis is simply "tacked in place" with interrupted sutures until it is firmly secured.

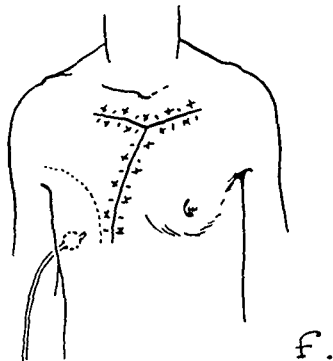
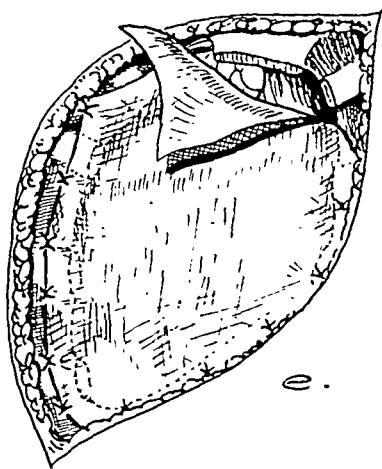


Fig. 1, Cont'd

e, Artist's conception of the mesh as it is employed to reconstruct the chest wall and prevent future paradoxical respiration. A double thickness of steel mesh is "tacked" over the bony thorax with interrupted fine silk sutures. *f*, Diagram of the completed operation showing closure of the skin flaps over the steel mesh. A Foley bag catheter is brought out through a stab wound in the sixth interspace for drainage of the right pleural space.

In our early cases, we employed only tantalum sutures for this procedure, fearing an unfavorable tissue reaction if a multiplicity of agents were employed. Experience has shown that this fear is unwarranted, and in the past two and one-half years we have employed fine silk to secure the mesh prosthesis. When the prosthesis is secured, it is covered by skin and subcutaneous tissue. It may be necessary to create large flaps of skin by undermining, and to employ releasing incisions in order to obtain satisfactory closure. In every instance it has been possible to effect primary closure of the wound edges, although grafts to the area of the releasing incision have been necessary. A firm dressing, applied with elastic bandage, need not be excessively bulky nor unduly padded to protect the wound.

In two patients the skin edges suffered necrosis because of excessive tension necessary for closure. The local necrosis produced separation of the wound down to the mesh. Ordinarily such a complication would jeopardize the retention of any foreign body prosthesis, particularly if a plate had been employed; however, in both instances the necrotic areas healed by granulation

how large defects can be repaired efficiently. I might add that I have had the same experience with the difference in tantalum mesh and stainless steel, and I advise the use of the latter, as did Dr. Effler. The fragmentation he speaks of does not occur in the center of the specimen (having removed one) but it is a tear that starts at the edge and goes right into the specimen; it does not break in the center or in an irregular fashion.

I arise mainly to mention a technique in the use of the mesh that Dr. Effler mentioned. He wants it to become a part of, to become incorporated into the body, and there is a method of using the mesh that will hasten this, particularly when there are some adjacent ribs left to which it can be fastened. In my hurry to leave Texas (not that I was in a hurry to leave, but in my hurried leaving) I left behind the lantern slides that had been prepared, so I call attention to the drawing on the blackboard. This is a cross section of two ribs; the intervening ribs have been removed and all the chest wall, as in one of the cases presented here. The periosteum was then removed from the side near the top edge of each rib, and peeled off the top surface and off the under surface, so that there was a flap of periosteum extending out from these ribs. The mesh was then inserted under the ribs, the ribs above and below the defect drilled, and wire sutures used to attach the mesh to the ribs. Then sutures were used to attach the periosteum as a flap to the wire mesh, so that when bone regeneration occurred it will incorporate itself directly into the wire mesh.

This method is also of value in repair of pulmonary hernias, where the periosteal flaps fail to bridge the space as in the second interspace anteriorly.

I must say again that I enjoyed Dr. Effler's paper very much.

DR ALEXANDER E. W. ADA, New York.—I would first like to thank Dr. Effler for a most excellent presentation. I have had parallel results in a smaller series of cases and have found this method most satisfactory. In no instance have I observed migration, fragmentation, or extrusion of the mesh or wound infection. A subcutaneous collection of serum has developed at the site of operation. This should be aspirated repeatedly by needle puncture through normal tissue a short distance from the wound.

In 1948 I first employed tantalum mesh to reconstruct the chest wall after surgical extirpation of a tumor. This case and a subsequent one were the basis of a report published in THE JOURNAL OF THORACIC SURGERY (21: 125, 1951). I would like to relate briefly the end result in the first case:

(Slide.) This is an anteroposterior x-ray film of the chest showing the tumor presenting itself in the right thorax and (slide) this is a photograph of the surgical specimen.

(Slide.) This is a postoperative x-ray film showing reconstruction of the defect in the chest wall and (slide) another view of the reconstruction.

The tumor was a plasma cell myeloma which was the only one visible on skeletal x-ray films before operation. The patient succumbed three years later to multiple myelomata in the Memorial Hospital. Dr. Higginbotham retrieved the tantalum mesh at autopsy. The mesh was found to be completely embedded in a thick layer of scar tissue creating a solid chest wall. The pleural surface was smooth and pearl white in color.

(Slide.) This is an x-ray film of a portion of the mesh showing it to be intact with the exception of a portion at the right, which was damaged in its removal.

(Slide.) I am indebted to a most industrious resident for this slide. It is a photomicrograph of a section taken through the tantalum mesh and scar tissue. Three wires are visible embedded in a homogeneous fibrous tissue with minimal round cell reaction which is represented by a few giant cells.

DR. HARVEY J. MENDELSON, Cleveland.—I wish to compliment Dr. Effler on this excellent series of cases, and I wish to mention my limited experience in three operative cases involving two patients.

One, which I will mention briefly, was merely the replacement of a defect following lobectomy in a patient who had had a shell fragment wound. This was a simple case;

and without residual sinus. In no case has it been necessary to remove a part or all of the mesh, nor have draining sinuses attributable to suture material occurred.

Early experience was confined to the use of tantalum mesh.* It proved satisfactory in the immediate postoperative period and the early impression was extremely favorable. However, follow-up studies have repeatedly shown that the tantalum mesh may fracture or disintegrate with the passage of time. For this reason, we changed to stainless steel mesh.† From our experience there seems to be little doubt that stainless steel is superior to tantalum for mesh; it withstands shearing stresses much more satisfactorily, and the factor of fatigability is less apparent.

SUMMARY

Defects of the chest wall secondary to extensive surgical procedures may be prevented by the use of mesh prosthesis which should be applied at the time of the definitive operation.

A series of twenty-one patients, operated upon at the Cleveland Clinic, have been presented; in each patient a mesh prosthesis has been successfully applied. There have been no clinical failures attributable to failure of the patient's tissue to tolerate tantalum or stainless steel mesh.

Mesh prosthesis has also been applied to reinforce reconstruction operations in the diaphragm; six patients were so treated for diaphragmatic hernia or eventration.

Experience in this series of patients suggests that stainless steel mesh is superior to tantalum mesh.

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DISCUSSION

DR. LAWRENCE M. SHEFTS, San Antonio.—The size of the surgical specimens is certainly a compliment to Dr. Effler's surgical ability; the size of the surgical specimen sent to the laboratory was almost as big as the patient. It demonstrates very vividly

*TM 53 gauge, .003 diameter, 50 x 50 mesh—Ethicon

†Surgaloy Product, No. 71, .003 diameter, 50 x 50 mesh—Davis and Geck.

If my memory is correct, Dr. Ada was one of the first to report on the use of tantalum mesh and reconstruction of the chest wall. I gathered from his remarks that he has not been impressed with fragmentation of tantalum mesh, certainly this has been the rule rather than the exception in my series. However, I believe it will be more apparent on the anterior chest wall than posteriorly. Someone, I believe Dr. Babcock of Philadelphia, has tested the shearing strength of various types of inert materials on a mechanical device and has demonstrated that stainless steel will tolerate this type of activity much better than tantalum.

Dr. Mendelsohn calls attention to the frequency of recurrence of fibrosarcomas in the chest wall. Many of the cases in this series were recurrent tumors, which emphasizes the necessity of an extensive well conceived operation that is correctly performed the first time. Experience encourages me to believe that there is almost no limit to the amount of chest wall that can be removed if a mesh prosthesis and an adequate skin closure can be employed. The type of operation that is inadequate in its basic conception will only be rewarded with recurrent neoplasm of the chest wall and necessitate multiple procedures with a correspondingly poor prognosis.

I appreciate very much the opportunity of appearing before this Association, again. I would like to thank the discussers of this paper.

following right lower lobectomy, the replacement of the defect which had been previously present solved the difficult closure problem and the patient had an uneventful recovery with no difficulty in re expansion.

The next patient was a young man who had had a fibrosarcoma of the chest wall locally excised previously, only one rib was removed. Within one year he had a recurrence, and the first slide shows this in the chest wall at this point. Within a few months it had grown to this size involving the left lung. The lesion was excised by a large en bloc excision, removing the fourth, fifth, sixth, and seventh ribs from the anterior to the posterior axillary line. Dr Effler mentioned and Dr Ada showed the problem of preventing paradox. It was thought best to prevent paradoxical motion with a wide sheet of 6 by 12 inch tantalum supported by a rib strut. This was done by bisecting the eighth rib longitudinally, preserving its periosteum, fracturing it posteriorly at its neck, and measuring it so that it coincided with the anterior limit of the excision at the fourth rib.

The interesting part of this is, unfortunately for the patient, that within a year he again had a recurrence of this fibrosarcoma in the lung, and on doing a pneumonectomy we obtained this specimen which includes the tantalum mesh chest wall, rib strut, left lung, and a portion of the left diaphragm.

(Slide) Here it is possible to see the outer surface of the specimen. I had resected a portion of the scapula in the previous operation so as to prevent a serious pocket from forming and there was no such pocket. The muscle had grown into the tantalum mesh, which had also fragmented. I do not have slides of the sections here, but there was muscle growing into the tantalum mesh with practically no reaction at the site of the tantalum.

(Slide) This shows the lung and a portion of the diaphragm removed with the tumor. The diaphragm here and the bronchus here, and there is some recurrent tumor in this area.

I present this case chiefly to show two things—a method of preventing as much as possible paradox by using a rib strut beneath the mesh, and also the fact that with tantalum mesh (or subsequently I have used stainless steel mesh) there is practically no reaction. Following pneumonectomy this patient had very little trouble. There was little or no paradox, and he had an uneventful recovery from the operation. Ultimate prognosis, however, is poor.

DR BERT H. COTTON, Los Angeles—I rise for three reasons. First, to say how much I enjoyed Dr Effler's excellent paper. Second, to concur with his encouraging observations by reporting fourteen cases with favorable results in block resection of the chest wall and prosthesis by stainless steel wire mesh. Third, to present one case which I thought might be of interest.

(Slide) This illustrates a case of block resection of a chest wall and pectoralis minor muscle for sarcoma, the attempted prosthesis, and the result. Here is seen the tumor involving the upper half of the right chest wall.

(Slide) The resected block of chest wall including the second, third, fourth, fifth, and sixth ribs, from the transverse processes to the sternum, and the lateral half of the seventh rib is shown here.

(Slide) This x-ray film shows an 18 inch sheet of heavy screen wire, No. 40 stainless steel mesh, molded to the contour of the right hemithorax.

(Slide) Here is a back view of the patient, the scapula has caused buckling of the posterior portion of the prosthesis, the mesh we felt was not heavy enough.

(Slide) The front view shows a satisfactory cosmetic result. There is slight prominence of the right pectoralis area due to the posterior buckling of the prosthesis.

Again, may I offer congratulations to Dr Effler.

DR EFFLER (Closing)—I am grateful to the discussants of this paper and in particular would like to thank Dr Shefts for his kind remarks. The method of applying a mesh which he has described is a definite refinement, and I am sure is an improvement over that presented today. I would like Dr Shefts to know that all the surgical specimens were not of the magnitude shown on the screen, knowing that some Texans would be present I brought only the largest.

further to overcome one remaining difficulty. It was found that even with the maneuver suggested by Wangensteen the ribbons were somewhat rigid and not long enough to adapt themselves easily to all corners of the empyema cavity; by excising the parietal pleura with its thick layer of fibrous tissue this difficulty was overcome, and the added advantage was gained of filling the space with muscle tissue, well supplied with blood, which rapidly threw out granulations to become adherent to the visceral layer. Since that time this operation has been used on many occasions for chronic cavities, both pleural and extrapleural in situation, and has proved extremely satisfactory. Only very recently have we learned that Grow gave an excellent description of the same procedure in 1946. However, judging by recent publications on the treatment of empyema and also from discussions with thoracic surgeons, it appears that this operation is little known and seldom practiced; Sweet in a recent textbook of thoracic surgery describes only the original Schede operation. It seems worth while to describe the operation again, indicating its advantages and limitations, in the hope that it will become more widely used.

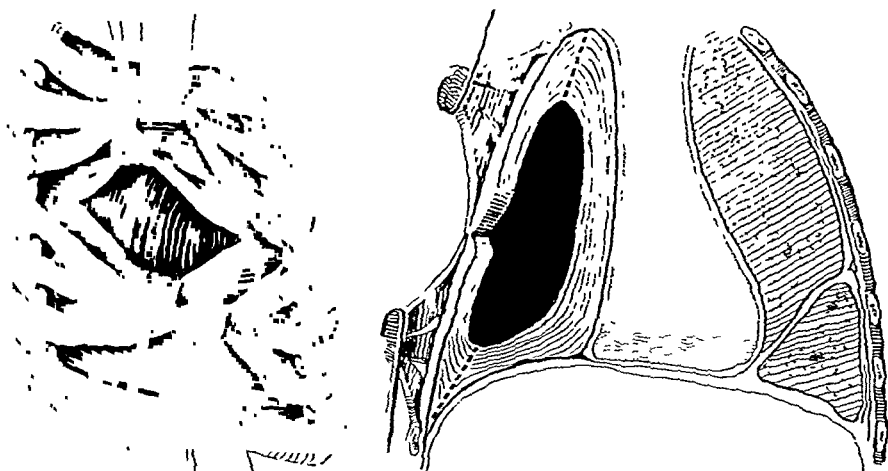


Fig. 1.—The diagrams illustrate the treatment of a chronic empyema following pneumonectomy. Guided by inspection of the open empyema cavity, all the ribs overlying the space have been resected and the intercostal muscle bundles freed. The parietal wall will be resected as indicated by the dotted lines.

THE METHOD

An incision is made which permits exposure of all the ribs overlying the cavity and three or four of the ribs over the center of the space are resected. The periosteum of each rib bed is then incised in a linear fashion, and by a combination of sharp and blunt dissection in the plane of the endothoracic fascia the intercostal muscle bundles between the resected ribs are freed intact and retracted out of the way. In the space so cleared the parietal pleura is widely incised and the interior of the cavity inspected. With the open cavity as a guide, it is then possible to resect all the ribs overlying it, in each case carrying the resection about one inch beyond the limits of the space. The corresponding

AN OPERATION FOR CHRONIC PLEURAL EMPYEMA

FREDERICK G. KERGIN, M.D., M.S., F.R.C.S.

TORONTO, ONT.

A PLEURAL empyema can be termed chronic only when, in spite of adequate drainage, the pleural space shows no appreciable tendency to decrease in size. The ideal solution for this situation is to obliterate the space by causing the lung to expand by the use of some form of decortication. However, there remains a group of patients to whom this ideal treatment cannot be applied. Occasionally decortication is technically impossible; more often the lung cannot, or should not, be expanded because of an intrinsic disease, and sometimes the lung has been removed previously. For these patients the surgeon must resort to thoracoplasty. If the process is truly chronic there is invariably deposition of fibrous tissue on the parietal pleura. This tissue may be sufficiently rigid so that even after removal of the ribs the chest wall cannot fall in to conform to the shape of the cavity and so lead to the healing of one surface to the other to produce obliteration of the space.

The operation described by Schede in 1890 was founded on an accurate knowledge of the pathology of chronic empyema and was a great step forward, but it has serious faults; it is shocking and mutilating, it sacrifices intercostal nerves with resulting cutaneous anesthesia and paresis of the abdominal wall, it leaves a large open wound requiring a long period of packing and dressing before healing is complete, and it leaves an unstable chest wall. After healing occurs, the rigid visceral layer of fibrous tissue lying on lung and mediastinum becomes thinner so that instability develops; paradoxical movement is a problem and the heart is unprotected. Various modifications of the operation have corrected some of the faults. The modifications of Roberts leave a stable chest wall but sacrifice the nerves, and the wound is packed open, which leads to slow healing. Heller, in 1934, described an operation in which, after removing the ribs overlying the cavity, the rib beds are incised to create a series of ribbons; each of these ribbons consists of an intercostal muscle with the accompanying vessels, nerve, underlying parietal pleura, and fibrous tissue. These ribbons are dropped into the cavity to act as space-fillers. In 1935, Wangensteen described the same procedure with certain modifications designed to make the ribbons more mobile, and so more adaptable to the shape of the cavity.

The Heller-Wangensteen operation is effective and overcomes all the serious faults of the Schede procedure: the intercostal nerves are preserved; the periosteum remains, allowing rib regeneration to provide a stable chest wall; and the wound can be closed with tube drainage. Some fifteen years ago Dr. N. S. Shenstone, Dr. R. M. Janes, and I modified the operation still

From the Department of Surgery, Faculty of Medicine, University of Toronto, and the Surgical Service of the Toronto General Hospital.

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4 wall, the space is filled with living tissue with excellent blood supply which rapidly throws out granulations to become adherent to the visceral wall. 5 fistulas may be dealt with directly, and the wound is sutured and heals by primary union. 6 The mobilized intercostal muscle bundles are of ample length and completely pliable so that they adapt themselves perfectly to the shape of the visceral layer leaving no unoccupied corners.

With certain modifications, mentioned below, the operation can be used for any chronic pleural or extrapleural cavity, provided there has not been a previous unsuccessful extrapleural thoracoplasty. In such a case it is not possible to resect the reformed ribs without damaging the intercostal muscle bundles. We have applied the operation to chronic nontuberculous empyema, to empyema following lobectomy or pneumonectomy, to tuberculous empyema with and without secondary infection, and we have used it to close cavities remaining after extrapleural pneumothorax or plombage therapy. Many of the tuberculous cases were operated upon before streptomycin was available but in only one patient, to be mentioned later, was there a tuberculous wound infection.

There has been no death attributable to this operation and only two complications. 1 One patient had a reactionary hemorrhage on the night of operation which required reopening the wound and packing; this delayed healing but the result was otherwise satisfactory. 2 The other complication emphasizes the one contraindication to this type of operation. One of our patients had an apical tuberculous empyema as the result of pneumothorax therapy and there was a small bronchial fistula; after treatment, as described previously, he developed a tuberculous subscapular infection which required treatment by a pedicle muscle graft for which pectoralis major was used. For a tuberculous empyema lying under the scapula the operation should be modified.

If the tuberculous empyema is complete, an upper seven-rib extrapleural thoracoplasty is done as a first stage. About four weeks later the lower part of the cavity is dealt with through a fresh incision, the intercostal muscles being freed as usual and the parietal wall excised. If, as is usually the case, the previous extrapleural thoracoplasty has failed to obliterate the upper part of the cavity and there is a narrow tunnel left posteriorly, one or two intercostal muscles may be divided anteriorly and tucked into this space as a muscle graft, and the operation on the lower chest completed in the usual fashion. This combined procedure is very effective, and, since the subscapular space is not opened at the second operation, there is no danger of infecting it.

To obtain collapse of a very thick-walled apical extrapleural space complicated by tuberculous infection, the result of extrapleural pneumothorax therapy, a different modification has been used on one occasion, with success. After resecting the overlying ribs and mobilizing the muscles as usual, the thick parietal wall was shaved down with a scalpel until it became thin and pliable, but care was taken not to enter the cavity. Aspiration of the contents then caused the parietal wall to collapse against the visceral surface, the bundles were laid on top and the wound closed.

intercostal bundles are then freed throughout their length, to result in the situation illustrated in Fig. 1. The bundles were shortened by the contraction of the fibrothorax; when liberated they lengthen and become quite slack, so are easily retracted, and later will fall into the cavity without tension. The parietal wall of the cavity is completely excised, taking care to bevel the edges in order to prevent kinking of the bundles and overhang of the edges of the cavity. The intercostal muscle bundles, of ample length, are simply laid in the cavity in parallel rows, as shown in Fig. 2, a tube laid over them, and the superficial muscles and skin sutured. It is of some advantage to institute closed drainage and after the first few hours to apply suction. Healing has been invariably by first intention; the tube can be removed in five to seven days.

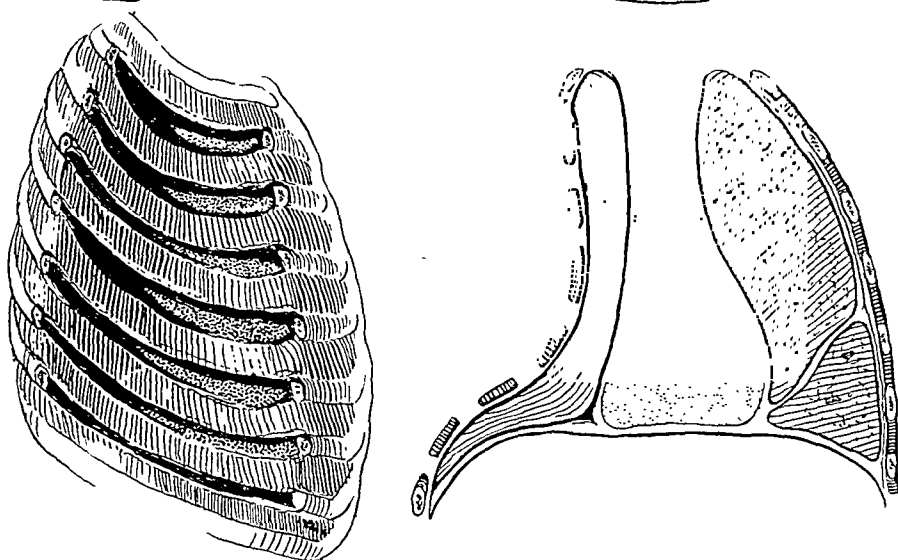


Fig. 2.—After resection of the parietal wall the muscle bundles are laid in the cavity. A tube is placed outside the bundles and the superficial muscles and skin sutured.

Because the mediastinum is protected by a rigid layer of fibrous tissue this operation produces no marked physiologic upset, the chief problem being loss of blood. If this is replaced in a quantitative manner, even very extensive thoracoplasty operations may be completed in one stage.

A bronchial fistula, if present, must be dealt with as seems most appropriate; occasionally the bronchus can be dissected free and sutured with an intercostal muscle to reinforce the suture line, more often the edges are simply freshened and an intercostal muscle sewn over or into the opening. In either case it is wise to lead a tube down to the neighborhood of the fistula and leave it there until there is good evidence that the fistula has healed; otherwise coughing may blow out air to create a small pocket around the opening of the fistula and this may persist.

DISCUSSION

The advantages of this method are that it is usually a ⁽¹⁾one-stage procedure, ⁽²⁾the intercostal nerves are preserved, ⁽³⁾the ribs regenerate to give a stable chest

EMERGENCY PULMONARY RESECTION FOR MASSIVE HEMOPTYSIS IN TUBERCULOSIS

C. A. ROSS, M.D.

EDMONTON, ALBERTA

ONE of the most alarming complications of pulmonary tuberculosis is massive hemoptysis. Such an occurrence terrifies the patient and distresses the physician.

Approximately one-third of patients with pulmonary tuberculosis will have hemoptysis but this reaches alarming proportions in only about 2 per cent of the cases.

Such gross hemorrhage is a dangerous complication of tuberculosis. The patient, who does not succumb to exsanguination or to suffocation by aspirated blood, very frequently develops a diffuse bronchiogenic spread of the disease which may cause death at a later date.

SOURCE OF HEMORRHAGE

It is recognized that major hemorrhages are usually associated with the chronic fibrocavernous type of phthisis. The bleeding is due to the rupture of a small aneurysm in the wall of a cavity in most instances. These aneurysms were first described by Fearn¹ in 1841, but Rasmussen of Denmark² did extensive work on this subject and the lesions have been named "Rasmussen Aneurysms." Most investigators have concluded that the vessels involved are branches of the pulmonary arteries but more recently Cudowicz³ has shown by an excellent series of investigations that the blood supply to the lung in these areas of fibrotic tuberculosis is mainly by way of dilated bronchial vessels and that these aneurysms are probably of bronchial rather than of pulmonary arterial origin.

METHODS OF TREATMENT

The usual methods used to control hemoptysis include: rest, sedation to calm the patient and to prevent excessive coughing, vitamin K and systemic coagulants. Some believe that ice bags applied to the chest may be of some value. Artificial pneumothorax, induced on the affected side, when possible, may be useful. Phrenic crush, pneumoperitoneum, emergency thoracoplasty and emergency plombage have all been employed for the control of hemorrhage from tuberculous disease.

Although gastric resection, in certain cases of massive bleeding of gastric origin, is an accepted procedure, the concept has not generally been extended to uncontrollable pulmonary hemorrhage, associated with tuberculous disease. A review of the pertinent literature reveals only one such case report,⁴ although it is most likely that there are unreported cases in which the operation has been performed.

*From the Aberhart Memorial Sanatorium.
Received for publication March 4, 1953.*

By modifications such as these, this method of thoracoplasty can be adapted to the treatment of any chronic empyema, provided the chest wall has not been mutilated by a previous thoracoplasty operation.

SUMMARY

1. The principles involved in the treatment of chronic empyema are discussed.

2. The disadvantages of the Schede operation and certain modifications of it are stated.

3. An operation, which is essentially the same procedure as that published by Grow, is described, with certain modifications which may be necessary for special problems. It has proved very satisfactory over a period of fifteen years in the treatment of all varieties of nontuberculous and tuberculous chronic empyema.

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Fig 1

Fig 1—Admission X-ray photograph, April, 1951, appearance remained essentially unchanged until hemoptysis one year later



Fig 2

Fig 2—X-ray film taken after first hemoptysis, showing diffuse bronchiogenic spread to the right lower lobe. Pneumoperitoneum has been partially removed because of dyspnea



Fig 3

Fig 3—Roentgenogram showing postoperative contralateral spread of disease



Fig 4

Fig 4—Pre-discharge X-ray picture showing patient's present status

It is recognized that pulmonary resection to control hemorrhage due to trauma is not an unusual occurrence. Such a procedure falls into an entirely different category from the case under discussion.

The following report is presented in an attempt to stimulate further interest in this procedure as a lifesaving measure in certain instances of hemorrhage from pulmonary tuberculosis.

CASE REPORT

Mrs. M. R., aged 45, was a woman of French and North American Indian extraction. She was admitted for treatment of pulmonary tuberculosis in April, 1951. At that time she had moderately-advanced disease involving the right lung. The x-ray pictures showed that the upper lobe was fibrotic and contained a large cavity while the lower lobe showed scattered nodulation and fibrosis. The sputum was positive for tubercle bacilli.

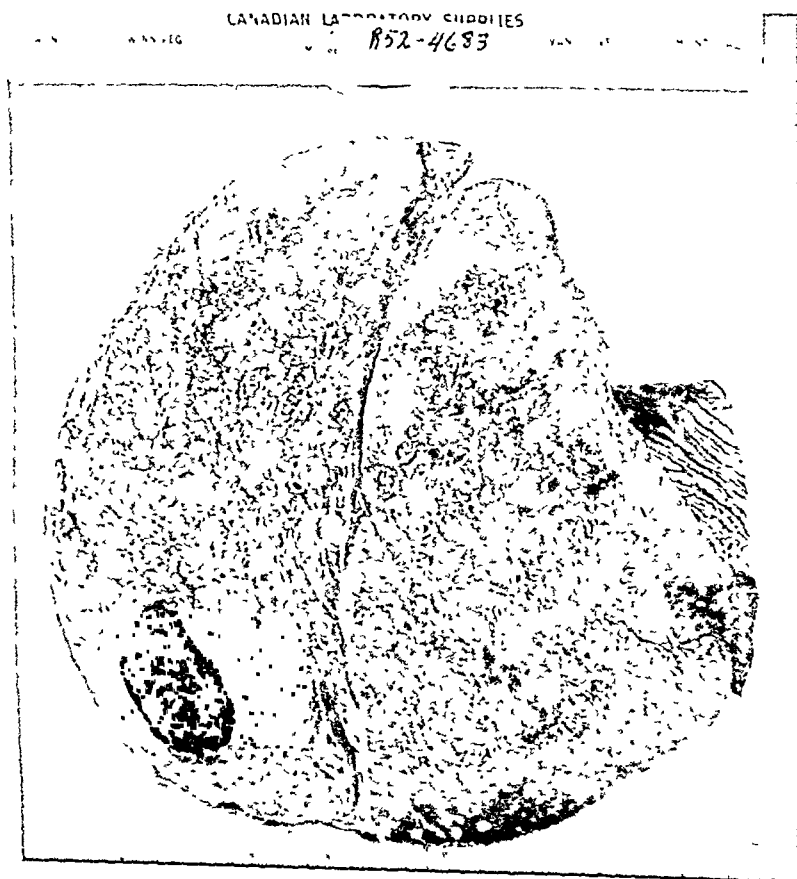


Fig. 5—Resected specimen. Right lung. Note large upper lobe cavity filled with blood clot and diffuse bronchogenic spread of disease.

She had had more than her share of tribulations. Past history included the loss of one eye in an accident; an appendectomy; severe burns of the face, trunk, and arms; and a cholecystostomy followed by a cholecystectomy which left a "postcholecystectomy syndrome." She also had an untreated congenital dislocation of the left hip.

Although it was obvious that "conservative" methods of treatment would be of no value in this case, a pneumoperitoneum was induced in an attempt to improve the patient's condition. Resection was considered, but postponed because the patient was not considered to be a fit subject for surgery at that time. Hemoglobin was 62 per cent of normal; albumin globulin ratio was reversed, the cephalin flocculation was two plus. She also had considerable gastrointestinal disturbance which was only partially controlled by diet and antispasmodics.

On May 21, 1952, after a rather large pneumoperitoneum refill, she began to cough up some bright red blood. The hemorrhage soon became profuse and during the following four days she had repeated large hemoptyses varying in amount from 10 to 20 ounces of blood at a time. By May 25 the bleeding had almost ceased. Hemoglobin determination at this time was 51 per cent of normal. A blood transfusion (500 cc) was given.

X-ray films at that time showed a diffuse spread of the disease to the lower lobe of the right lung, and the temperature was elevated to 103° F.

On May 29, she began to have further profuse hemoptyses. This continued during the day and by early evening she was in extreme shock and it was not possible to determine the blood pressure. Further transfusion was started but replacement did not keep pace with the continued loss of blood. A second transfusion was started in another limb and with both running under pressure, she was taken to the operating room for an emergency pneumonectomy.

After induction of the anesthesia, she was bronchoscoped and considerable blood was aspirated from the trachea and bronchi. A Thompson bronchus block was introduced into the right main stem bronchus and the balloon inflated. This controlled further flooding of the opposite lung with blood. With the patient in the lateral position, a right thoracotomy was done and a rapid pneumonectomy performed. Mobilization of the lung, done extrapleurally, was difficult because of extremely dense adhesions. During this procedure the azygos vein was inadvertently torn causing troublesome hemorrhage. The bronchus was closed with a single row of interrupted vertical mattress sutures.

Postoperatively the patient's condition was only fair. Blood pressure remained at approximately 70 to 80 mm mercury, systolic for twenty-four hours, in spite of what is usually considered to be adequate blood transfusion. She had in all 8,000 cc of blood, including the two bottles which were running at the time she was taken to the operating room.

Temperature, which had been 104° F immediately prior to the operation, dropped to normal the next day and remained so until the sixth postoperative day when it again rose to 101° F and a definite contralateral spread of the disease was noted.

Dihydrostreptomycin (1 Gm daily) was started on May 22, after the first hemoptysis. Following the operation 1 Gm twice daily was given. This was continued until July 4, when it was changed to 1 Gm three times weekly and so continued until October 7. Streptomycin had to be discontinued at this time because of complaints of nausea which seemed to be associated with the use of the drug. PAS, 12 Gm daily, was given in conjunction with the streptomycin from May 30, onward. Isonicotinic acid hydrazine, 200 mg daily, was commenced on June 19, and has been continued until the present writing. PAS solution containing 10 Gm of the drug was introduced into the right pleural space every other day for two weeks postoperatively.

A small pneumoperitoneum was maintained until November 1, to help reduce the size of the right hemithoracic space.

The patient was discharged from the Sanatorium on Jan 13, 1953. At present she is well, steadily gaining weight and x-ray pictures show no evidence of active disease in the contralateral lung. Examination of sputum and fasting gastric juice on repeated occasions have not shown the presence of tubercle bacilli on either smear, culture, or guinea pig inoculation.

DISCUSSION

It is interesting to note that even though the operation was performed in the face of an acute exacerbation of the tuberculous process, and on a patient who was a very poor surgical risk, the outcome was gratifying. It is also noteworthy that a contralateral spread of the disease appears to be controlled by prolonged antibiotic therapy.

Technical considerations of importance are: (1) Excellent anesthesia is most necessary. (2) Large amounts of blood transfusion must be given, particularly during the operation. (3) Endobronchial tamponade prior to beginning surgery is the ideal method of positively controlling the hazard of aspiration of blood by the other lung. (4) Although speed in surgery is not generally important with the advantages of present-day anesthesia and blood replacement therapy, this is an instance when speed is necessary. Such a patient cannot stand prolonged operative procedure. (5) Prolonged antibiotic therapy is necessary in addition to surgery.

It is difficult to list indications for surgical intervention in these cases but it is obviously unwise to attempt the procedure unless the contralateral lung is either free of disease or has only minimal disease present, and that should preferably be in a stable state. Conservative measures should first be tried to control the situation, but surgery should not be delayed until a massive contralateral spread of disease has occurred or the patient is in such poor condition as to be beyond surgical help.

Usually the simpler operation of pneumonectomy will be preferred to lobectomy but in certain instances the latter may be indicated.

SUMMARY

A successful emergency pneumonectomy for massive hemoptysis complicating pulmonary tuberculosis has been presented.

Some suggestions have been made regarding the treatment of these cases.

I would like to thank Dr. Nelson Nix of Edmonton who very ably handled the difficult anesthetic problem that this case presented, and the Medical Staff of the Aberhart Memorial Sanatorium for their assistance and cooperation.

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Original Communications

THE PRESENT CHAOS REGARDING RESECTION OF RESIDUAL CASEOUS LESIONS IN PULMONARY TUBERCULOSIS

EDWARD J. O'BRIEN, M.D., DETROIT, MICH., ARTHUR C. MILLER, M.D. (BY INVITATION), LOMA LINDA, CALIF., PAUL T. CHAPMAN, M.D. (BY INVITATION), KOERT KOSTER, M.D. (BY INVITATION), AND PAUL V. O'ROURKE, M.D., DETROIT, MICH.

A FEW years ago, a somewhat generally accepted agreement on the indications for resection in pulmonary tuberculosis had been reached. Medlar's¹ excellent contribution regarding the residual caseous lesion and simple excision, however, started a wave of enthusiasm (prematurely) for resection of almost all residues remaining after chemotherapy treatment, regardless of the length of time it was used. This view still persists, in spite of the fact that investigators, including Medlar himself and his associates, now almost unanimously agree that we have no accurate evaluation of the pathologic and bacteriologic aspect of many of the lesions in question, nor any proof that they should be resected. Many lesions, including apparent scars, contain caseous foci. D'Esopo² states that while it appeared at the time Medlar's¹ contribution was made caseous residuals should be resected, the past two years of research prove this very questionable.

That the pathogenicity of tubercle bacilli may be affected by their accommodation to incarceration within the necrotic lesion is generally conceded. Acid-fast bacilli can be recovered from many of these lesions in smears and cultures. This is especially true of open, cavernous lesions, and to a much lesser extent in closed ones. Medlar³ obtained positive cultures in only 7 per cent of the closed lesions and an average of 40 per cent in all specimens. Our findings corroborate this. However, the important question, whether many of these bacilli are virulent, is unfortunately still controversial in some quarters.

Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 30, 1953.

Announcement

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The 34th annual meeting of the American Association for Thoracic Surgery will be held May 3, 4, and 5, 1954, in Montreal, Que., Canada. Headquarters will be at the Sheraton-Mount Royal Hotel.

Requests for Hotel Reservations

These should be mailed *directly* to the Reservation Manager, Sheraton-Mount Royal Hotel, Montreal, Que., Canada. Please mention this Association, type of accommodation desired, date, and approximate hour of arrival. If accommodations are desired elsewhere, please communicate directly with hotel of your choice.

Thoracic Surgical Forum

After due consideration, the Council has decided to try an experiment by assigning one morning session to a "Thoracic Surgical Forum" for the presentation of short papers on current thoracic research, anatomy, modified surgical techniques, etc. Papers at this session will be limited sharply to ten minutes (including the showing of lantern slides or other illustrative material) with three minutes as the maximum discussion of each paper.

These papers will be published together in one issue of THE JOURNAL OF THORACIC SURGERY. Maximum length: 3,000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts for Papers

Abstracts for the presentation of papers at the 1954 meeting, including papers before the Forum, must be received on or before January 1, 1954, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Forum" or "For Regular Program."

Five, repeat five, copies of each abstract should be sent to the Secretary of the Association, Dr. Paul C. Samson, 2938 McClure St., Oakland 9, Calif. They should not be sent to the Editor.

The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Jan. 1, 1954, to be considered for action in Montreal. Applications received beyond this deadline will be deferred for consideration until 1955.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the sponsoring statement on the application form, the sponsors must submit a separate letter concerning the applicant direct to Dr. Lyman H. Brewer, III, Chairman of the Membership Committee, 2010 Wilshire Blvd., Los Angeles, Calif. Completed application forms should likewise be sent to Dr. Brewer. These regulations are at the direction of the Council and were made effective in 1952 at Dallas,

concentration are actually bacteriocidal. Before chemotherapy, it was thought that cavity closure, and healing resulted after the bronchial opening became occluded, rendering the closed inspissated material more susceptible to the physiochemical environment.

It is the small, nodular, apparently arrested residue present after one or more years of medical management, however, that is the most controversial. Canetti⁷ concludes that dead bacilli exist, in these lesions, with or without chemotherapy. Sweany⁸⁻¹⁰ believes their life under these conditions depends on the length of time they are imprisoned, and believes they are dead after five years. Mahon¹¹ states his studies show that streptomycin was rarely present in the center of the lesion, and that acid-fast bacilli found there could not be cultured. Murphy¹² questions whether we are justified in recommending even wedge resections in these lesions. Auerbach³ says it is impossible to determine whether unobliterated residuals should be left in situ or resected. It seems incongruous to treat a hospitalized patient for twelve to eighteen months or more, watch the lesion clear from an extensive infiltration to a small residue that has remained stationary for months (with negative sputum for a year or more), and then debate whether to send him home or resect. (For brevity, the lesion just described will be referred to as a "nubbin" in this paper.)

That we see more filled cavities under chemotherapy is unquestionable, but this is difficult to correlate with Auerbach's findings. It is thought by some that chemotherapy, especially INAH, dries up the material and prevents its expulsion.

Many relapses or extensions of disease, before chemotherapy, obviously came from expelled caseous foci, but now this is not apparent. It seems from our experience that in a larger percentage of patients reactivation occurs in other lesions which previously existed. Examination of many serial roentgenograms seems to confirm this.

It has been our opinion that noncavernous lesions with somewhat extensively mixed residues after long chemotherapy, with little or no change in x-ray appearance, should be resected. We have no proof now, however, from bacteriologic studies, that even this is correct. Many feel that apparently thick-walled cavities should be resected early, but it is not controversial that cavity walls thin out markedly, under chemotherapy, and often become much smaller with walls so thin they are difficult to see. These lesions, with considerable assurance, can be expected to close and heal with some form of collapse therapy—pneumothorax, thoracoplasty, or phrenic added to their other therapy. Unfortunately, these procedures are now virtually obsolete, although there are many many thousands of individuals who have been made well and have remained so after their use. That these methods should be discarded, because in the past they were given with very poor indications and technique, is difficult to understand. It has been our thought that in filled cavities resection has seemed indicated; but again research does not confirm this theory.

The argument for widespread resection is that the patient's future would be less hazardous if all lesions including "nubbins" were removed. It is also

Steenken⁴ reported a few patients undergoing Isoniazid therapy, with positive sputum on cultures, which could not cause disease in guinea pigs. Many other investigators have tried to produce active disease from cultures and caseous material after continuous long-term chemotherapy and have failed. In Medlar's³ few reported completed tests, guinea pigs inoculated with considerable material containing numerous bacilli failed to show evidence of disease six months after inoculation. In old apparently healed lesions many investigators think that the bacilli are dead, regardless of chemotherapy.

It must be remembered that the paper of Medlar and Welles and their associates,¹ which started the present resection scramble, was based on theory, not on proved evidence. Their opinions have mostly changed now regarding resection, but they believed in it then and presented the paper for discussion and further investigation. This has been pursued by research and medical men, as well as surgeons. It is unfortunate that further research was not done before surgeons began cutting with reckless abandon.

The question of which lesions to resect is not definitely established. There is a wide divergence of opinion on the subject. There are those who blindly follow Medlar's¹ unproved hypothesis and resect almost all residues with or without long periods of chemotherapy. Others, floundering in the maze of pathologic and bacteriologic reports of our researchers, are not sure of the pathogenicity of these lesions and are much more conservative. There seems to be no disagreement that open cavities are potentially most dangerous. D'Esopo states that cavities not closed in six months under chemotherapy usually never close under this regime alone, and that if cavities remain open, sputum, which may be negative for months, will again turn positive. We concur in this. Auerbach⁵ has shown that, under chemotherapy, re-epithelization occurs at the bronchocavitory junction and often extends some distance into the cavity wall itself. The tubercle bacillus is an aerobic creature. A patent bronchial junction should add to the difficulty of causing it to die. It is difficult to understand how an open cavity can be sterilized unless complete epithelization occurs. Auerbach⁵ believes that granulation tissue at the cavitory junction, before chemotherapy, causes a ball valve effect resulting in a ballooning of the cavity, and that these agents, which have greatest effect on surface lesions, clear the pathway and allow the cavity to reduce in size or close.

Why the contents of the cavity are not expelled, under these circumstances, is perplexing. Medlar³ states these usually contain neutrophils which help liquefy the caseous material, and allow them to flow out. He³ also agrees that in closed lesions the physiochemical environment is probably the reason bacilli here are apparently not virulent, but he thinks that it is only an assumption that unculturable bacilli are dead and not temporarily dormant. He and others suggest that new culture media and animals be used for experimentation. Dubos⁶ states that long-chain fatty acids are powerful antimicrobial agents, and that these are released by lipolytic enzymes, during necrosis, with resulting caseous material. He also states that these fatty acids, and lactic acids in low

Continually changing chemotherapy programs have resulted in many interruptions of treatment. Our best results and fewer reactivations occurred in those who had its continuous long-period use. Most patients presented received streptomycin and PAS alone.

No one at this time can know definitely the exact status of resection in closed lesions. But, our researchers now inform us that it is very questionable they should be resected. They give their blessing only to its use in open cavities. Time and further research must tell us much more about its application in all residues. In the meantime resection of "nubbins" goes on with total disregard of the findings of investigators. It seems very probable that not much of anything is accomplished for the patient, except unnecessary invalidism, by this surgery. Reports of results following resection for these residues are meaningless for who can tell that these lesions would have ever caused future trouble if they were not disturbed?

The entire treatment of the caseous lesion at present is confusing and chaotic. When we are more enlightened, however, it seems that indiscriminate resection will be abandoned. Individual lesions will then, we hope, be given more intelligent management.

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DISCUSSION

DR. EDWARD S. WELLES, Saranac Lake.—I quite agree with Dr. O'Brien, and I think his paper has expressed perfectly the whole situation. I do not come here as an advocate or an apostle of resection. We presented a paper about small resections in 1951 before this Association at Atlantic City, reporting a small series of operations dating from January, 1950. We said at the time that this was a study, and that study is still going on and we could now report a much larger series of cases—which I am not going

true, however, that a patient is better off with no surgery at all if he does not need it. This serious, painful, mental and physical experience should not be taken lightly. Deaths do occur from resection, as do bronchopleural fistulas, remaining lobes that fail to re-expand sufficiently, empyema, added thoracoplasty, Schede operations, as well as early and late exacerbations of disease. The percentage of these occurrences is small, and they are now less frequently encountered. However, it is 100 per cent in those who get them.

It is our belief that it is impossible, from roentgenograms or sputum studies, to know whether a small caseous area in the center of apparently firm, stationary, fibrous tissue is hazardous. We can rely only on the findings of investigators. Thinking of the extensive, caseous disease, which so frequently exists under thoracoplasty and knowing that the greater percentage of these patients lose their positive sputum, become well, and remain so, it is difficult to become excited over a "nubbin" encased in fibrous tissue. It frequently happens that more disease is found at operation than was apparent in the x-ray picture. Areas of so-called "satellites" often surround the "nubbin," and other infiltrations, not suspected preoperatively, show evidence of previous disease. After long chemotherapy, the former are now much less frequently observed. These areas, rather than the "nubbin" itself, may actually be the cause of reactivations after cessation of treatment. The surgeon does not remove all disease by wedges, segments or lobes, if disease has existed elsewhere previously.

Scars or "nubbins" are present in many thousands of people throughout the country, and most of them are, and have been, living normal lives for years. Nobody thinks of hospitalizing them, and resecting these lesions, unless reactivation occurs. Lesions, after long therapy, that still appear active or have open cavities are not discussed here. We are primarily concerned with the stationary, apparently healed "nubbin." Steele¹³ reported about 10 per cent of his reactions for residuals proved to be unnecessary, but who can say what percentage of the remaining ones would ever reactivate? The length of chemotherapy treatment has been steadily increased. It is obvious that short-term treatment was unsatisfactory. If resistance does not develop, who can predict what the optimal period of therapy will be before considering resection or other procedures?

Since December, 1951, we have discharged over 600 patients after long-term chemotherapy for further ambulatory treatment in the out-patient department and have watched them carefully to date. Only eight have been rehospitalized. In this group there were 176 who had resection alone, 79 who had thoracoplasty, and 403 who had only chemotherapy. Three reactivations occurred in the resection group, none in the thoracoplasties, and five in those treated medically only. Two of the five without surgery showed no roentgenologic increase of disease, but were rehospitalized because of one or two positive sputums. These positive sputums have not been verified after long rehospitalization. The three reactivations after resections occurred in over-distended remaining lobes. It is too early to draw conclusions, but we present these figures for what they may be worth.

THE USE OF ISONIAZID AS A PROPHYLACTIC ANTIBACTERIAL AGENT IN PULMONARY RESECTION FOR TUBERCULOSIS

PRELIMINARY REPORT

MAX E. CHILDRESS, M.D. (BY INVITATION), MILDRED E. THOREN, M.D. (BY INVITATION), AND ALBERT C. DANIELS, M.D. (BY INVITATION)
WEIMAR, CALIF.

INTRODUCTION

THE advent of antimicrobial therapy has widened the scope of pulmonary resection in tuberculosis. However, prolonged usage and injudicious application of these agents, especially streptomycin, have created limitations. These are manifested by postoperative complications due to the development of resistance by the tubercle bacillus. It became apparent that the hazards of surgery were increased when such a state did develop. Thus, patients were denied the surgical procedure which might well have returned them to a useful place in society.

The introduction of a new suitable agent for protection during excisional therapy was needed to increase the salvage rate in pulmonary tuberculosis. It follows that such an event would allow the prolonged use of streptomycin and para-aminosalicylic acid without fear of the development of resistant strains of tubercle bacilli to these agents.

Published results of the investigations as to the effect of Isoniazid (isonicotinic acid hydrazide) on experimental tuberculosis have revealed the following: (1) tuberculostatic and tuberculocidal action in vitro,¹ (2) marked antituberculous activity in vivo,^{1, 2} (3) healing of progressive tuberculosis in guinea pigs caused by tubercle bacilli resistant to streptomycin and para-aminosalicylic acid,³ and (4) low drug toxicity.^{4, 5}

When the suppressive effect of Isoniazid on human pulmonary tuberculosis was demonstrated,^{6, 7} it was felt that this drug warranted a clinical trial as a prophylactic antibacterial agent for pulmonary resection in tuberculosis. Accordingly, the following study was undertaken.

METHOD OF STUDY

Following the recommendation for pulmonary resection, the patients on the present series were accepted for Isoniazid therapy in consecutive order. No attempt at case selection was made.

A minimum period of two months from the time of operation was arbitrarily chosen to note the appearance of possible surgical complications while on Isoniazid therapy. The medication was commenced forty-eight hours prior to

From Weimar Joint Tuberculosis Sanatorium.

Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 30, 1953.

to do, no figures, no statistics—and can only say that the percentages which Dr. O'Brien mentioned (and very thoughtfully did not show on the screen) agree very closely with ours. The number of recurrences after resection is very small, and the number of recurrences in a series treated with chemotherapy and then sent home when treatment was stopped with no resection is just about the same. So we do not know.

I have been interested chiefly in one feature of this question on which I might give Dr. O'Brien a figure; that is treatment of minimal tuberculosis. We have a small series over the years, and have now operated on between 40 and 50 patients with minimal tuberculosis and resected the lesions that we could find. Dr. O'Brien asks, "How do you know that those people did any better than if you had not resected them?" We have only one figure to go on; that is the statistics brought out by Dr. Robert Mitchell three or four years ago on minimal tuberculosis. Mind you, this is not moderately or far advanced tuberculosis treated and brought back to a small shadow. This is original minimal. In a large series in over twenty five years, 35 per cent of them relapsed, among the 40 or 50 patients we have treated so far, no single one has relapsed and I still think it is worth trying if that much improvement can be attained.

I congratulate Dr. O'Brien on presenting his chaos.

DR JOSEPH GORDON, Ray Brook—I should also like to express my appreciation of Dr. O'Brien's paper and tell you about four pegs that we are pinning up as a current concept for the indications for resection with combined chemotherapy.

First, enough experience has been gained thus far to indicate that the open cavity 4 cm. or larger fails to respond to combined therapy in a sufficient number of cases to make this, as a single measure of treatment, reasonable. These patients, on the other hand, are the ones from whom resistant organisms emerge, and we are ultimately obliged to try to salvage such patients in a poorer state when the chemotherapeutic agent is not nearly so effective.

Second, we recognize that there are certain patients who show rather marked toxic reaction to the drug relatively early, whose compensatory mechanisms, such as eyes and ears, neuromuscular, and cardiovascular systems, are originally impaired. They appear to show marked changes early, and should not be carried on a long term chemotherapeutic program.

The third group, which is a relatively small one, but has the possibility of increasing as chemotherapy alone in unsuccessful cases goes on, is the group of patients who come to us with primary resistant organisms. In that group, of course, prolonged therapy, even with the addition of another agent, is not commonly successful, so that they might be approached relatively early with resection.

In the fourth group, lacking long term follow up data, includes the residual necrotic lesion that is perhaps 3 cm. in size or larger. We can draw on certain past experiences, as Dr. O'Brien has done with other forms of treatment. The solitary lesion under pneumothorax and under thoracoplasty often shows a good initial result, remaining negative in a fair number of instances. Others are seen to shell out with the result that a positive sputum and spread might occur. In such a group of cases, under chemotherapy, there is a reasonable prospect of the emergence of resistant organisms; therefore the patient will be handicapped as regards future treatment. Such foci then are best treated by resection despite the favorable chemotherapeutic initial result.

of the streptomycin-resistant patients had received previous treatment with streptomycin and para-aminosalicylic acid. The exception was a young girl who probably was exposed to an open case of pulmonary tuberculosis which had been treated with streptomycin.

SPUTUM

The tracheobronchial secretion was considered to be positive* for acid-fast bacilli preoperatively in fifteen patients and negative† in eight. Of the eight negative sputum cases, two were indeterminate lesions preoperatively and the diagnosis was in doubt. In both of these acid-fast bacilli were demonstrated in the resected specimen. The remaining six patients were advised to have pulmonary resection because the stability of their lesions seemed unlikely, even though their sputum was negative.

OPERATIVE PROCEDURE

Operative technique is a secondary consideration in the present study. However, a few sentences will assist in clarifying the prophylactic objective sought by means of the use of Isoniazid. The classification of operations is:

1. Pulmonary resection	23
a. Pneumonectomy	1
b. Lobectomy	8
c. Lobectomy and segmental resection	5
d. Segmental resection	5
e. Subsegmental resection	4
2. Concomitant thoracoplasty	3
3. Resection under thoracoplasty	12

The primary aim in operative technique was to conserve as much parenchyma as possible. This principle involved dissection close to the palpable and visual residual disease.

PLEURAL CONTAMINATION

Bronchiogenic tuberculosis may begin as a segmental or subsegmental disease. It may soon lose its respect for anatomic boundaries. As the inflammation progresses intersegmental planes may be penetrated and passed. Thus, not infrequently portions of the adjacent segments need also to be excised.

While following the diseased process through the pulmonary parenchyma a suppurative area is easily inadvertently punctured. Therefore, while attempting to perform a segmental resection for disease that has partially involved an adjacent segment an escape of purulent material is not unlikely.

A critical observation was made for gross visible pleural contamination. If a drop of purulent material was spilled, the pleural cavity was considered contaminated. If in the severance of diseased tissue caseation necrosis was seen, the pleural space was likewise considered contaminated. Eleven of the twenty-three cases had gross pleural contamination. Unquestionably, if larger volumes

*Persistently or intermittently positive by smear, concentrate, or culture four months preoperatively.

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operation. It was administered orally in the dosage of 200 mg. per day or 3 mg. per kilogram of body weight. During the immediate postoperative phase when the patient was unable to tolerate oral intake, Isoniazid was given intramuscularly in the same dosage. It was then recommenced by the oral route at the appropriate time. The original plan included an attempt to diminish copious tracheobronchial secretions by instituting Isoniazid therapy two weeks prior to surgery. No such problem arose during the present interval of observation. However, consideration for this modification of drug therapy seems worthy, as the volume of tracheobronchial secretion has been noted to decrease during Isoniazid therapy.

The efficiency of Isoniazid was to be measured by the number and extent of postsurgical complications due to tuberculosis. Thus, the object of this essay is to answer the question, "Does Isoniazid afford adequate antibacterial protection during the operative period and for a minimum postoperative period of two months against the tubercle bacillus?"

PROCEDURE

During the interval from Oct. 13, 1952, to Jan. 26, 1953, twenty-six pulmonary resections were performed. The medication under discussion was used on these patients in rotation. Three of the above twenty-six were excluded from the series because they had received a previous course of Isoniazid. It was presumed that their tubercle bacilli were resistant to Isoniazid.

We are presently concerned with twenty-three operations on twenty-three patients. These patients ranged in age from 15 to 61 years. Of the twenty-six, twelve of the patients were women and eleven were men.

The indications for pulmonary resection in this group approximate that seen in the current literature. In general, the indications fall into the following patterns: (1) thoracoplasty failures; (2) residual disease after prolonged antituberculosis therapy; (3) negative sputum with residual disease, as noted by roentgenogram, which is not likely to remain stable; and (4) negative sputum, indeterminate pulmonary lesions.

It should be understood that the listed surgical indications apply only to the group under observation. They are not meant to represent a complete discussion of the criteria for pulmonary resection in tuberculosis.

PREOPERATIVE ANTITUBERCULOSIS MEDICATION

As would be expected the majority of the twenty-three had had antituberculosis medication before surgery. Twenty had received a minimum of one and a maximum of three courses of streptomycin and para-aminosalicylic acid. Within this group, two had received thiosemicarbazone. One patient, of the twenty-three, had received para-aminosalicylic acid alone. Two had not had any antimicrobial therapy.

STREPTOMYCIN SENSITIVITY

The tubercle bacilli of eight of the twenty-three patients were resistant to streptomycin. Three were completely resistant to 100 μ g, two to 10 μ g. Seven

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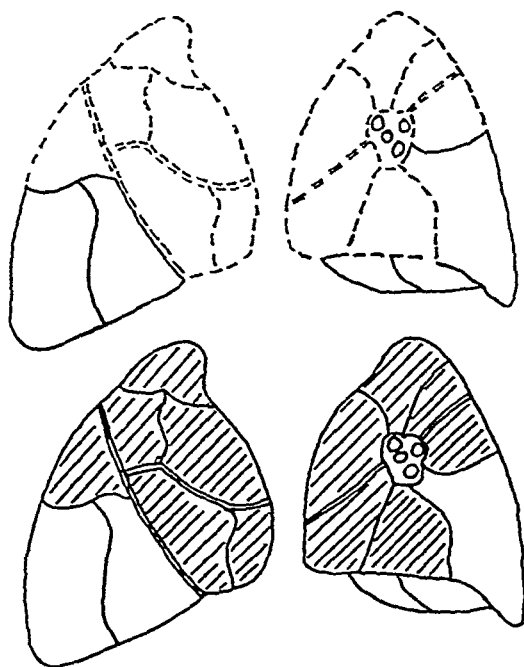


Fig. 2.—I. C. Age 44 years. There was pleural contamination. The diagonal lines represent fibrocaseous tuberculosis with cavitation, tuberculous bronchitis, and pulmonary fibrosis; broken lines the resected parenchyma.

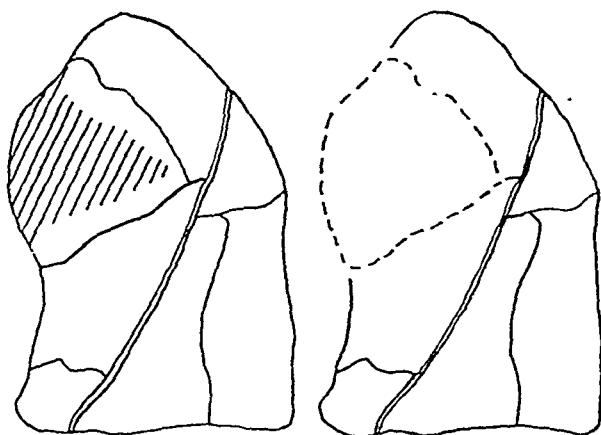


Fig. 3.—T. K. Age 23 years. Diagonal lines represent fibrocaseous tuberculosis and tuberculous bronchitis, broken lines the resected parenchyma. Pleural contamination occurred. The patient was streptomycin resistant ($3 \mu\text{g}$).

of parenchyma had been resected, the incidence of pleural contamination would have been less. But, such action would have defeated the principle of pulmonary tissue conservation. These latter cases will be considered in more detail.

CASE REPORTS

CASE 1.—J. H., an 18-year old girl, had never had a sputum positive for acid fast bacilli. Preoperative therapy consisted of pneumoperitoneum, streptomycin, and para amino-salicylic acid on a presumptive diagnosis of tuberculosis. A fibrocaseous nodule was resected from the apical segment of the right upper lobe. It contained acid-fast bacilli on smear, but they failed to grow in culture. A small amount of suppurative material contaminated the pleural cavity at operation. The postoperative course was uneventful, and the sputum has remained negative for acid fast bacilli by cultural methods. The histologic diagnosis of the resected specimen was fibrocaseous tuberculosis.

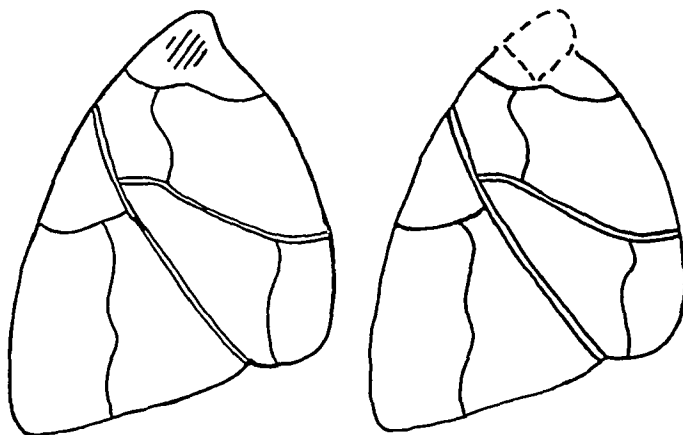


Fig 1—J. H. Age 18 years. There was pleural contamination. The diagonal lines represent fibrocaseous tuberculosis, broken lines, the resected parenchyma.

CASE 2.—I. C., a 48 year old woman, had a persistently positive sputum for acid fast bacilli. She had far advanced bilateral disease. Preoperative therapy consisted of pneumoperitoneum, thoracoplasty, streptomycin, and para amino-salicylic acid. The right lung with the exception of three basal segments was excised. Caseous material escaped when the medial basal segment was removed. The postoperative course was complicated by jaundice during the eighth postoperative week. This was considered to be homologous serum in type and she has recovered from it. The postoperative sputum is negative for acid fast bacilli by culture. Histologically the lesion was fibrocaseous tuberculosis with cavitation, tuberculous bronchitis, and pulmonary fibrosis.

CASE 3.—T. K., a 23 year old woman, had moderately advanced bilateral disease and a negative sputum. Preoperative therapy consisted of pneumoperitoneum, streptomycin, and para amino-salicylic acid. The patient underwent an anterior segmental resection of the left upper lobe. Suppurative material contaminated the pleural space. Smear from this lesion was positive for acid fast bacilli, but the culture was negative. Streptomycin resistance to $3\mu\text{g}$ was present. The postoperative course was complicated by homologous serum jaundice. The sputum remained negative by cultural methods. The histologic diagnosis included fibrocaseous tuberculosis and tuberculous bronchitis.

CASE 4.—X. Y., a 26 year old woman with a negative sputum, underwent a subsegmental resection of the posterior segment of the right upper lobe. Preoperatively pneumoperitoneum, streptomycin, and para amino-salicylic acid were used therapeutically for minimal unilateral

plasty, streptomycin, and para-aminosalicylic acid for unilateral far-advanced disease. The apical posterior and anterior segments of the left upper lobe and the superior segment of the left lower lobe were excised. Suppurative material escaped into the pleural cavity at operation. Postoperatively the patient's course was complicated by a persistent fever which responded satisfactorily to penicillin and Terramycin. The cause of this fever remains obscure. Sputum studies reveal the persistence of acid-fast bacilli. Histologically the lesion was fibrocaseous tuberculosis with tuberculous bronchitis and cavitation.

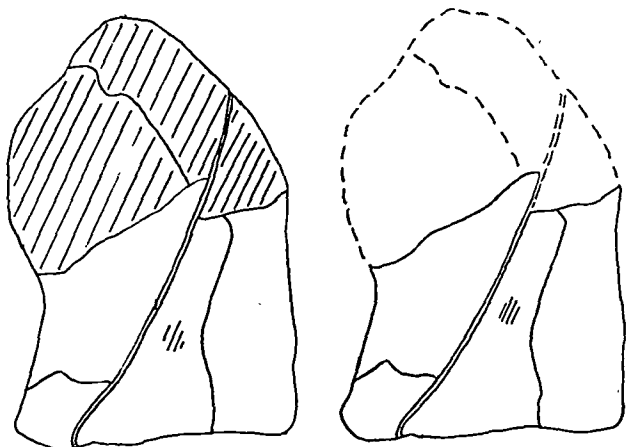


Fig. 6.—V. P. Age 61 years. Patient had diabetes mellitus. Diagonal lines represent fibrocaseous tuberculosis with tuberculous bronchitis and cavitation; broken lines, the resected parenchyma. Pleural contamination occurred.

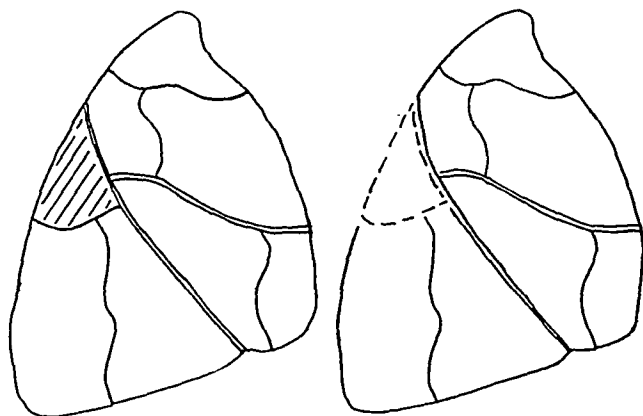


Fig. 7.—B. C. Age 18 years. Diagonal lines represent fibrocaseous tuberculosis and tuberculous bronchitis; broken lines, the resected parenchyma. Pleural contamination occurred. The patient was streptomycin resistant (100 μ g).

CASE 7.—B. C., an 18-year-old girl, had minimal unilateral disease with a positive sputum. She had had no preoperative therapy yet the tubercle bacilli were completely resistant to streptomycin to 100 μ g. A right superior segmental resection was done and a blocked cavity inadvertently opened. The postoperative course was marked by persistent fever and a local accumulation of fluid opposite the resected segment. The fever gradually subsided to normal under the influence of penicillin and Terramycin. The pleural fluid, as noted by a roentgenogram, is clearing. Sputum is negative to concentrate, but the culture has not yet been completed. Histologically the lesion is fibrocaseous tuberculosis with tuberculous bronchitis.

disease. Suppurative material from a blocked cavity escaped during operation. Histologically the disease was fibrocaceous tuberculosis and pulmonary fibrosis. The postoperative course was benign and the sputum remains negative to culture.

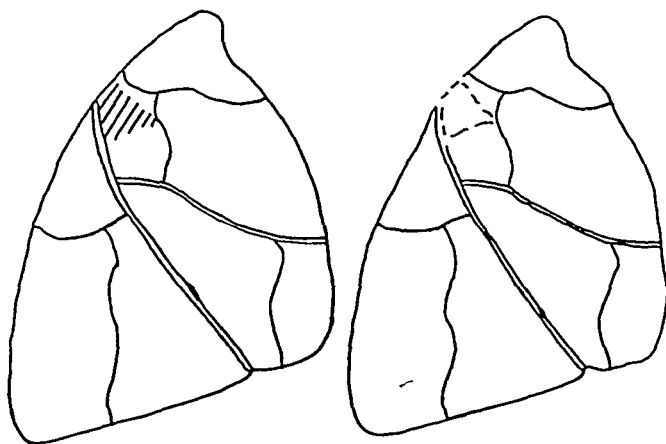


Fig. 4.—N. Y. Age 26 years. Diagonal lines represent fibrocaceous tuberculosis and marked pulmonary fibrosis; broken lines the resected parenchyma. Pleural contamination occurred.

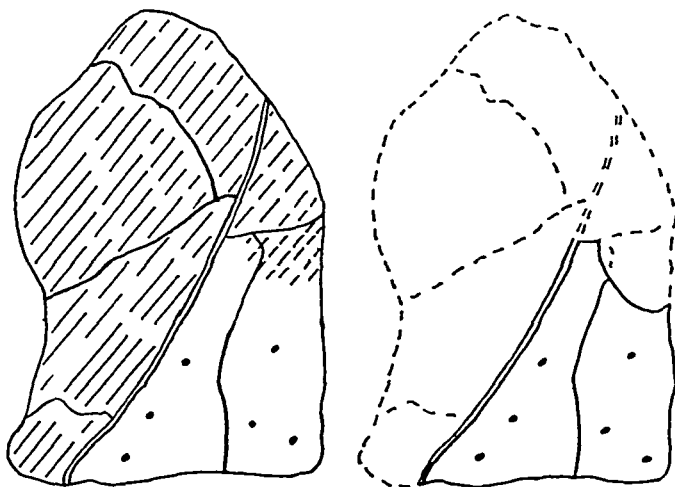


Fig. 5.—D. C. Age 46 years. Preoperative thoracoplasty. Diagonal lines represent airless lung with fibrocaceous tuberculosis; broken lines, the resected parenchyma; dots, scattered nodular disease. Pleural contamination occurred. The patient was streptomycin resistant (10 μ g).

CASE 5.—D. C., a 46-year old woman, had far advanced bilateral pulmonary disease. The sputum was negative preoperatively. Therapy before operation consisted of pneumo peritoneum, phrenic crush, thoracoplasty, and several courses of streptomycin and para amino salicylic acid. Streptomycin resistance was present to 10 μ g. The left lung was excised with the exception of the basal segments. Suppurative contamination of the pleura occurred. Acid-fast bacilli were demonstrated in the contaminating exudate and grew on culture. Post-operative course was benign and the sputum remains negative to culture. Histologic diagnosis was fibrocaceous tuberculosis.

CASE 6.—V. P., a 61-year old man, had diabetes mellitus. Sputum had been persistently positive for acid-fast bacilli. Preoperative therapy consisted of pneumoperitoneum, thoraco

of the middle lobe was compromised. It was necessary to excise this latter segment. The postoperative period was uneventful, and the sputum is now negative by culture. Histologically the disease was classified as fibrocaseous tuberculosis with tuberculous bronchitis and cavitation.

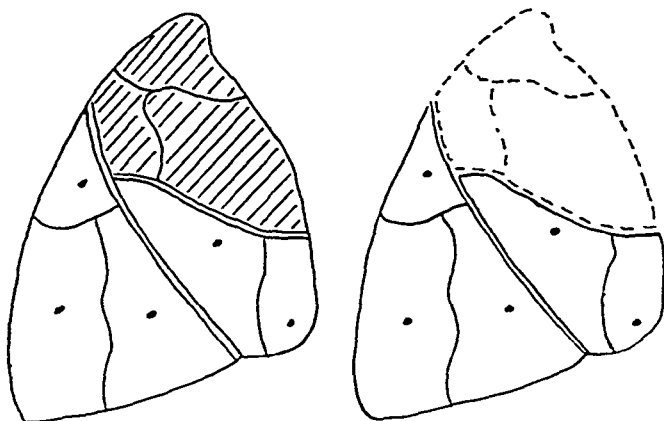


Fig. 10.—K. K. Age 23 years. Diagonal lines represent fibrocaseous tuberculosis with tuberculous bronchitis; broken lines, the resected parenchyma. The patient was streptomycin resistant ($3 \mu\text{g}$). Pleural contamination occurred.

CASE 10.—K. K. This 28-year-old woman had bilateral far-advanced disease with a persistently positive sputum. A cavity was opened during the process of a right upper lobectomy and concomitant thoracoplasty. Preoperative therapy consisted of pneumoperitoneum, streptomycin, and para aminosalicylic acid. Streptomycin resistance to $3 \mu\text{g}$ was present. Postoperative phase was uneventful and the sputum is negative to culture.

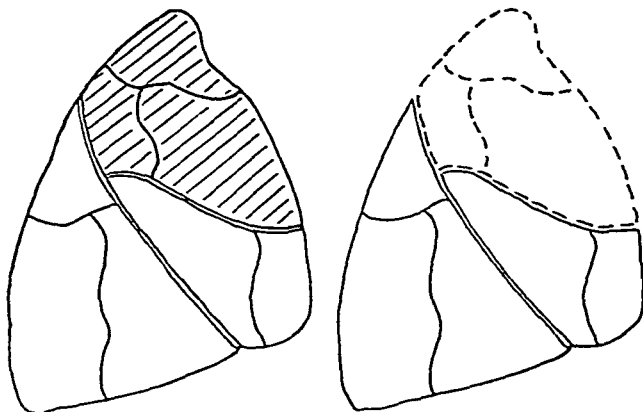


Fig. 11.—E. D. Age 31 years. Diagonal lines represent fibrocaseous tuberculosis with tuberculous bronchitis and miliary dissemination and chronic granulomatous pleuritis; dots, scattered nodular disease; broken lines, the resected parenchyma. (The concomitant modified Schede thoracoplasty is not shown.) The patient was streptomycin resistant ($100 \mu\text{g}$).

CASE 11.—E. D. This 31-year old man had far advanced disease which was bilateral. Also present was an ipsilateral, draining, mixed tuberculous empyema. Previous therapy consisted of pneumothorax, pneumoperitoneum, phrenic crush, thoracoplasty, cavernostomy, streptomycin, and para aminosalicylic acid. Streptomycin resistance was complete to $100 \mu\text{g}$. A right upper lobectomy and concomitant modified Schede thoracoplasty were done. The

CASE 8.—G. G., a 32 year old woman with a positive sputum, had an apical posterior segmental resection of the left upper lobe. Preoperative treatment consisted of phrenic crush, pneumoperitoneum, and paraaminosalicylic acid for unilateral moderately advanced disease. Caseous material was exposed at operation. The postoperative course was benign. Sputum studies show a negative concentrate, but the culture is not completed. The histologic diagnosis is fibrocaseous tuberculosis.

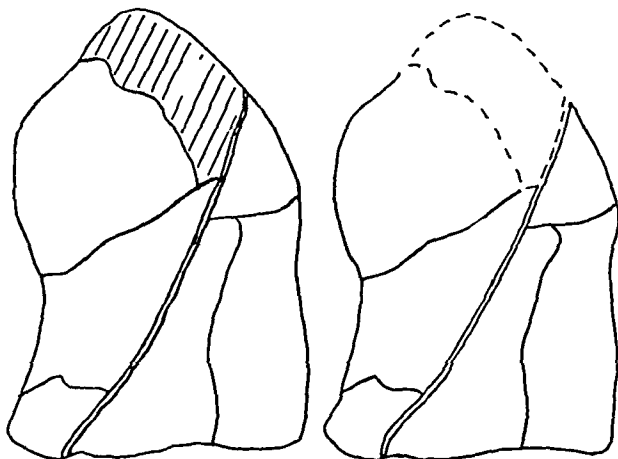


Fig 8—G. G. Age 32 years. Diagonal lines represent fibrocaseous tuberculosis, broken lines, resected parenchyma. Pleural contamination occurred.

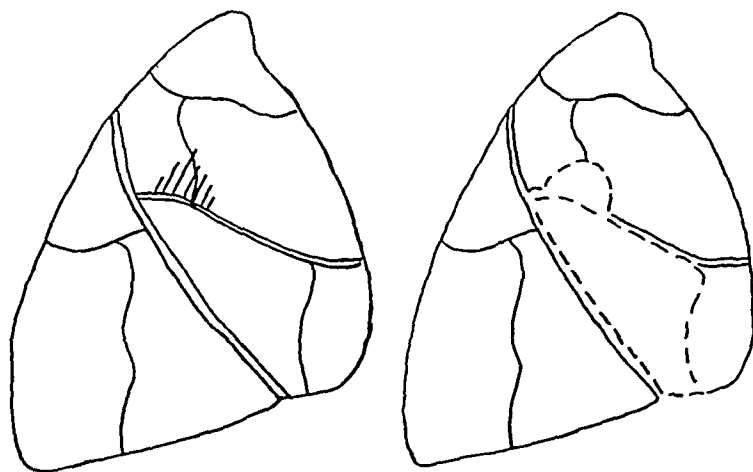


Fig 9—M. D. C. Age 31 years. Diagonal lines represent fibrocaseous tuberculosis with tuberculous bronchitis and cavitation, broken lines, the resected parenchyma. Pleural contamination occurred.

CASE 9—M. D. C. This 33 year old woman had a coincident condition of neurofibromatosis (von Recklinghausen's disease). She had far advanced bilateral disease with a contralateral healed, mixed tuberculous empyema. Sputum had been persistently positive. Preoperative therapy consisted of a left pneumothorax, left thoracostomy, pneumoperitoneum, streptomycin, paraaminosalicylic acid, and thiosemicarbazone. A subsegmental resection of the posterior and anterior segments of the right upper lobe exposed the interior of a cavity. During exposure of the lesion through inflammatory tissue the bronchus to the lateral segment

CONCLUSIONS

The question asked earlier in the discussion, "Does Isoniazid afford adequate antibacterial protection during the operative period and for a minimum post-operative period of two months against the tubercle bacillus?" may be answered in the affirmative. This implies proper timing of the medication so that its period of action is before the bacterial organisms become resistant to Isoniazid.

SUMMARY

1. Twenty-three patients undergoing pulmonary resection for tuberculosis were administered Isoniazid as the prophylactic antibacterial agent during the operative period and postoperatively for a minimum of two months. The efficiency of the drug was measured in terms of postoperative complications due to tuberculosis.

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lateral margin of the empyema communicated with the free pleural space at the end of the operation. Postoperative sputum is negative by culture and the empyema space is epithelized. Histologic diagnoses include fibrocaseous tuberculosis with tuberculous bronchitis and miliary dissemination, tuberculous sinus tract of the skin, and granulomatous pleuritis.

DISCUSSION

The clinical evaluation of a drug is difficult to perform with exactness due to the many variables and lack of complete control. However, certain trends become apparent. The fact that there were no complications attributable to tuberculosis indicates that Isoniazid did, indeed, play the role of a prophylactic agent.

The bacteriologic study of the resected specimens was commenced late in the initially described time interval. Of the twenty-three specimens, three were positive by smear and negative by culture for acid-fast bacilli, four were positive to both smear and culture, one was negative to smear with unfinished culture, and fifteen were not examined. Included in the group of positive smear and positive culture are specimens from the two patients who had not received preoperative streptomycin and para aminosalicylic acid.

No analyses or conclusions were attempted from such a small series. The apparent inconsistencies of smear and cultural examinations of resected lesions are well recognized. Medlar⁹ speculates that these discrepancies are due to: (1) antimicrobial therapy resulting in dead organisms, (2) biochemical properties of the necrotic lesion resulting in dead organisms, and (3) insufficiently sensitive cultural methods.

Bacterial resistance to Isoniazid develops in approximately two to three months.¹⁰ After resistance has developed, it is likely that the prophylactic antibacterial effect would be greatly diminished or lost. However, that was neither proved nor disproved by the work in this study.

Following the pattern of streptomycin, it is becoming increasingly difficult to find a patient who has not had a course of Isoniazid. Such a state may jeopardize the future of patients needing a pulmonary resection. It is suggested that Isoniazid be withheld from cases in which a pulmonary resection may be necessary in the future.

RESULTS

Twenty-three pulmonary resections for tuberculosis were completed on twenty-three patients.

TWENTY-THREE PULMONARY RESECTIONS

Postoperative nontuberculous complications	5
Homologous serum jaundice	2
Chest wall abscess	1
Local accumulation of pleural fluid	1
Persistent fever, unknown origin	1
Postoperative tuberculous complications	0

There were no bronchopleural fistulas, no tuberculous empyemata, no contralateral spreads, or reactivation of previously quiescent disease. In one case, the contralateral active disease improved as noted by roentgenogram.

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The question asked earlier in the discussion, "Does Isoniazid afford adequate antibacterial protection during the operative period and for a minimum post-operative period of two months against the tubercle bacillus?" may be answered in the affirmative. This implies proper timing of the medication so that its period of action is before the bacterial organisms become resistant to Isoniazid.

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DR. A. C. DANIELS, San Francisco.—A good deal of work on Isoniazid has been done at Weimar Sanatorium and I thought this would be an appropriate time to call to the attention of this group the emergence of strains of tubercle bacilli that are resistant to this drug.

(Slide.) The top line as you will note is Isoniazid alone, and at the end of six months 90 per cent of the strains of tubercle bacilli are resistant to Isoniazid. When it is combined with streptomycin there is essentially the same percentage, 86.9 per cent. With Isoniazid and PAS 80 per cent of the strains of organisms are resistant at the end of six months. When Isoniazid, streptomycin, and PAS are given together, 46 per cent of the strains within six months are resistant to isoniazid. This is a series of about 100 patients, all of whom still had positive sputum at the time the evaluation was carried out, so that we know that these particular strains have developed this resistance.

This is to point out the importance (and I think that is what we learn from Dr. Childress's paper) of preserving Isoniazid as a chemotherapeutic agent for the surgical treatment of tuberculosis and not let it be dissipated at some earlier time when it is not as useful to the patient. So far as we are concerned, the only time that Isoniazid is indicated in the medical treatment of pulmonary tuberculosis is in tuberculous meningitis and miliary tuberculosis, and in those few patients in whom the disease is so far advanced that it is given as a last hope, where no surgical treatment of the patient is anticipated. We hope that the word will get around that Isoniazid should not be used indiscriminately and that it should be reserved for the time of pulmonary resection, because in our hands when used alone it has been a most formidable agent against the tubercle bacillus.

THE INFLUENCE OF LONG-TERM CHEMOTHERAPY ON THE SURGERY OF PULMONARY TUBERCULOSIS

JOHN D. STEELE, M.D., B. G. NARODICK, M.D. (BY INVITATION), AND
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MILWAUKEE, WIS.

THE feasibility of the use of long-term streptomycin and PAS in the therapy of pulmonary tuberculosis from the standpoint of toxicity was first pointed out in 1949 by D'Esopo.¹

Pathologic changes in pulmonary lesions found after prolonged chemotherapy were described about one year later by D'Esopo, Ryan, and Medlar.² The surgical excision of necrotic pulmonary foci following long-term original courses of streptomycin and PAS was reported to this Association two years ago by Ryan, Medlar, and Welles.³ It was suggested at that time that the results from original courses of long-term chemotherapy were more satisfactory than the results from retreatment courses and that the problem of bacillary resistance was not an appreciable one during original courses provided, of course, that combined therapy with streptomycin and PAS was used. It has been shown by the same group of workers that tubercle bacilli can be cultured more readily from the lesions of patients receiving retreatment courses than from those receiving original courses of chemotherapy.^{4, 5}

The use of long-term chemotherapy has altered profoundly our own indications for resection and collapse therapy in the treatment of pulmonary tuberculosis. Prolonged chemotherapy is particularly effective in patients having lesions with an appreciable exudative or pneumonic component and is less effective in those having chronic, fibrotic, destructive, irreversible lesions.

In order to appreciate the problems of surgical treatment arising in patients with lesions which show good response to long-term chemotherapy, it is necessary to review certain pathologic concepts. These concepts apply regardless of the extent of the disease.

Medlar^{2, 3, 6} has pointed out that as areas of tuberculous pneumonia resolve they may first, either heal by complete resolution or scar formation or, second, undergo necrosis with the formation of an irreversible, necrotic focus which essentially is a tuberculous abscess. The discharge of debris from such a necrotic focus into a bronchus leads to a tuberculous cavity. Chemotherapy apparently hastens the changes which occur in pneumonic lesions. Cavities which are present at the start of long-term chemotherapy frequently become filled with caseous material during treatment and small necrotic areas less than 5 mm. in diameter may sometimes become encapsulated completely. It has recently been observed by Auerbach and his co-workers⁷ that the bronchocavitary junction may epithelize as the result of long-term chemotherapy and prevent obliteration of the

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Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 28, 29, and 30, 1953.

bronchial lumen at this site which, in turn, may be an important factor in preventing cavity closure. Auerbach has further noticed that the inspissated, caseous contents of a filled cavity may be invaded by leukocytes which may produce a liquefaction and evacuation of the contents, leaving a cavity lined with a smooth, glistening surface.

As the result of these observations and of our own observations on resected specimens, we believe that cavities present after long-term original courses of chemotherapy probably fall into three separate categories. In the first group are the filled cavities, the contents of which may vary from hard caseous to liquid purulent material; in the second, there are the "clean" cavities of Auerbach lined with smooth, glistening surfaces which can often be demonstrated roentgenographically to have been filled at some point during chemotherapy; in the third group are the cavities which remain open during the entire course of chemotherapy, and which are usually lined by a "dirty," necrotic, caseous surface. Tubercle bacilli can be cultured much more readily from the walls and contents of these "dirty" cavities than from those in the first two groups (see Table II).^{5, 8}

From a practical standpoint, when a patient with disease of relatively recent origin or disease containing an appreciable exudative component is treated with long-term chemotherapy to a point where, first, roentgenograms taken two months apart show no change and all cavities are filled or have been lost to view and, second, examinations of pulmonary secretions are negative on culture, the problem then arises whether to resect the residual lesions or to leave them alone. We have chosen to use resection for such patients except for those who have extremely small exudative lesions prior to chemotherapy.

We realize that final evaluation of our resection program will require a fairly long follow-up period. The incidence of reactivation of disease in the resection group must be compared with that in a comparable group which has received long-term chemotherapy without resection.

We do not believe that collapse therapy can be considered logically as an alternative in these cases because of the nature of the pathology of the residual lesions.

We do, however, believe there still is a place for collapse therapy, particularly thoracoplasty, in the treatment of tuberculosis. The relative frequency with which collapse therapy procedures were used in relation to resection at our sanatorium during 1952 is shown in Table I.

TABLE I. SURGICAL AND COLLAPSE THERAPY PROCEDURES USED DURING 1952 AT MUIRDALE SANATORIUM

PROCEDURE	PATIENTS
Resection	128
Thoracoplasty (definitive)	17
Decortication	3
Paraffin pneumonolysis	1
Phrenic paralysis	1
Pneumoperitoneum	1
Pneumothorax	0

In general we have used thoracoplasty in patients with cavities remaining open during long-term chemotherapy and who have also had disease which appeared too extensive for resection. In addition, we have been inclined to use thoracoplasty when the operative risk of resection was estimated to be abnormally high. We do not consider that we have abandoned other collapse therapy procedures entirely and intend to use them in occasional selected cases in the future. We feel that long-term chemotherapy is so much more effective than the so-called temporary collapse therapy procedures that we are fully justified in not using them to any appreciable extent.

Our present program of resection of residual necrotic foci following long-term chemotherapy started in June, 1951, when we operated on a patient who had received an original course of streptomycin and PAS of sixteen months' duration. From June, 1951, to December, 1952, we performed 182 pulmonary resections on 146 patients. One hundred twenty-five of these resections were for residual lesions in patients prepared with original courses of streptomycin and PAS for four months or more; twenty-one patients were prepared with long-term retreatment courses; the preparation or indication for thirty-six other patients who underwent resections for pulmonary tuberculosis performed during this same period are shown in Table II.

TABLE II. MISCELLANEOUS RESECTIONS FOR TUBERCULOSIS IN 34 PATIENTS

	RESECTIONS	CULTURE POSITIVE
Cavities unfilled during chemotherapy	10	7
Less than 4 mo. chemotherapy preparation	13	2
Isoniazid preparation 1-4 mo.	4	1
8 mo.	5	1
Other	4	0
Total	36	11

The type of operations performed on our patients who received long-term chemotherapy in preparation for resection is shown in Table III. The great majority had small resections, either wedges or segments or both. Wedge resections were performed during 93 of the 146 operations. These wedge resections were actually subsegmental resections since all dissections were carried out in anatomic planes. The pneumonectomy was performed because the pulmonary artery was torn during a segmental resection.

We believe that the use of long-term chemotherapy made it possible to perform small resections in the majority of our patients and thus preserve con-

TABLE III. TYPE OF PULMONARY RESECTIONS IN 112 PATIENTS WITH FOUR OR MORE MONTHS' PREOPERATIVE SM AND PAS
(ORIGINAL AND RETREATMENT COURSES)

Exploration only	4
Wedge(s) only	63
Segment(s) only	39
Segment(s) plus wedge(s)	27
Lobectomy only	9
Lobectomy plus wedge(s)	3
Pneumonectomy	1
Total	146

siderable pulmonary function. In other words, the percentage of entire lobes resected would have been much higher if these patients had been prepared for resection with short courses of chemotherapy.

Pulmonary function, as measured by maximum breathing capacity and walking ventilation, was not affected in the great majority of our patients having small resections, even in the bilateral cases.

The greatest disadvantage we have found in the performance of small resections has been the relatively high incidence of postoperative complications. These complications and the treatment required in each group are listed in Table IV. We should like to emphasize: (1) that the end results in all of these patients have been good, (2) that none of the complications was tuberculous, and (3) that there was no mortality in this group of 146 resections. We feel that the high incidence of peripheral lung leaks, as distinguished from large bronchial leaks, is a reasonable price which has been paid for the preservation of a maximum amount of lung tissue. The lung leaks considered as complications were either persistent or recurrent. We believe that it is usually safer to perform a secondary thoracotomy than to rely on the use of catheters and needles over a protracted postoperative period. This is particularly true in the case of postoperative hemothorax. It is possible that two empyemas could have been prevented if hemothoraces in these patients had been evacuated early by secondary thoracotomy. Our space-filling thoracoplasties were small ones and resulted in no appreciable loss of pulmonary function.

TABLE IV. SIGNIFICANT COMPLICATIONS AND TREATMENT REQUIRED
146 RESECTIONS—112 PATIENTS

I. <i>Lung leaks</i>		19
Secondary thoracotomy	13	
Catheter aspiration	5	
Space-filling thoracoplasty	4	
II. <i>Hemothorax</i>		6
Secondary thoracotomy	3	
"Varidase" (successful)	1	
Space-filling thoracoplasty	2	
III. <i>Empyema (pyogenic)</i>		5
Thoracotomy for drainage	5	
Modified thoracoplasty	3	
Total complications		30 (20.0%)

Table V shows the distribution of the complications according to the types of small resections. Although a number of different operative techniques and postoperative routines were utilized, the incidence of complications was evenly distributed throughout the series.

TABLE V. SIGNIFICANT COMPLICATIONS IN 129 SMALL RESECTIONS

	CASES	PER CENT	NO.
Wedge(s) only	63	9	14
Segment(s) only	39	8	20
Segment(s) plus wedge(s)	27	11	40

We have been particularly interested in the bacteriology of the resected lesions from patients who have received long-term chemotherapy. For the most part, the material from different lesions in the same resected specimen was pooled for bacteriologic examination. Lesions were incised for examination by the surgeon under aseptic conditions at the conclusion of each operation. Cultures and guinea pig inoculations were done on untreated material and also on another portion digested with trisodium phosphate. Cultures were made on Löwenstein-Jensen's medium. Guinea pig pathogenicity and drug sensitivity tests were made on all positive cultures.

Fortunately, the number of our patients receiving long-term *retreatment* courses of streptomycin and PAS was relatively small. The reason for this is that we had *complete control* of the choice and administration of the chemotherapy received by most of our patients. Furthermore, we were aware two years ago of the probable advantages of original over retreatment courses. Five of the twenty-one resected specimens in this group were positive on culture (Table VI). This incidence corresponds closely to the findings of others in this category.^{4, 5, 8} All of our patients had drug-sensitive bacilli at the time of retreatment.

TABLE VI. BACTERIOLOGY OF RESECTED LESIONS IN 16 PATIENTS HAVING RETREATMENT COURSES OF SM AND PAS FOR MORE THAN FOUR MONTHS
TOTAL THERAPY—VARIOUS REGIMENS

MONTHS CHEMOTHERAPY	RESECTIONS	CULTURE AND/OR GUINEA PIG POSITIVE
4-8	5	1
8-12	9	3
12-18	5	1
18-24	2	0
Total	21	5

In the group of patients who had *original* courses of streptomycin and PAS for more than four months (Table VII), 125 resections were performed on 96 patients. In other words, twenty-nine patients had bilateral and sixty-seven had unilateral resections. One hundred two patients were prepared with eight or more months of chemotherapy.

TABLE VII. BACTERIOLOGY OF RESECTED LESIONS IN 96 PATIENTS HAVING ORIGINAL COURSES OF SM AND PAS FOR MORE THAN FOUR MONTHS

MONTHS CHEMOTHERAPY	RESECTIONS	SMEAR AND/OR SECTION POSITIVE	CULTURE AND/OR GUINEA PIG POSITIVE	NONCASEOUS LESIONS OR NONE
4-8	23	14	1	5
8-12	54	37	3	3
12-18	46	26	7	4
18-24	2	2	0	0
Total	125	79	11	12

Cultures of the sputum or gastric contents of eighty-eight of these patients were positive for tubercle bacilli prior to the start of chemotherapy; the lesions of the other eight patients were active from a roentgenographic standpoint.

The pulmonary secretions of only one of the ninety-six patients were known to be positive on culture just prior to resection; the secretions of eighty-six patients were negative; the secretions of nine patients early in our series were not examined immediately before resection.

Roentgenologic stability of lesions for a minimum of two months was required prior to thoracotomy.

The lesions in 105 of the 125 lungs showed moderate to marked roentgenologic improvement under chemotherapy while the lesions in the other 20 remained stationary.

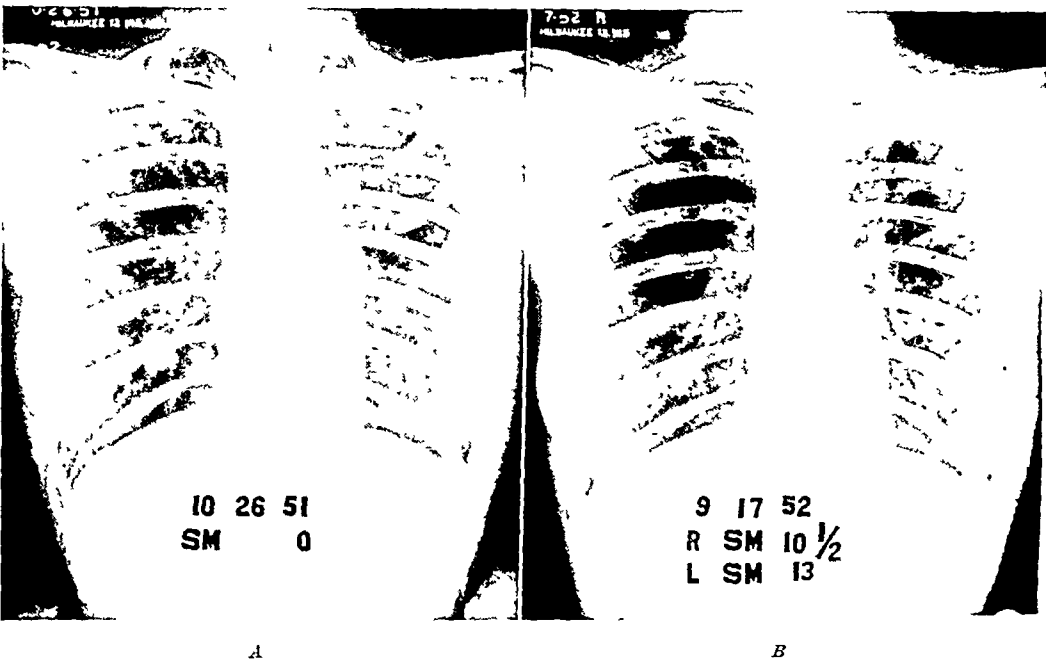


Fig. 1 (Case 1) —The patient was a white woman, 26 years old. A, Roentgenogram at start of chemotherapy. Note large subclavicular cavity on left. B, Roentgenogram following ten and one-half months of chemotherapy consisting of daily doses of streptomycin and PAS. Preoperative film. For operative findings see Fig. 2, A and B.

Four patients having cavities lined with smooth, glistening surfaces which had shown roentgenographic evidence of having been filled at some point during chemotherapy are included in this group of 96 patients. No patient having a cavity which had not closed or which had not been filled during chemotherapy is included.

The discrepancy between the number of positive smears and/or acid-fast bacilli found on tissue section and the number of positive cultures or guinea pigs brings up the question as to whether such tubercle bacilli which can be seen but cannot be grown are dead or alive. Some investigators^{9, 10} believe that such bacilli in most lesions are actually dead. On the other hand, it has been suggested that these bacilli may have lost their ability to reproduce because they may be affected by a substance or substances which, if neutralized, might allow them to reproduce again.¹¹ This is a question which cannot be answered at the present time.

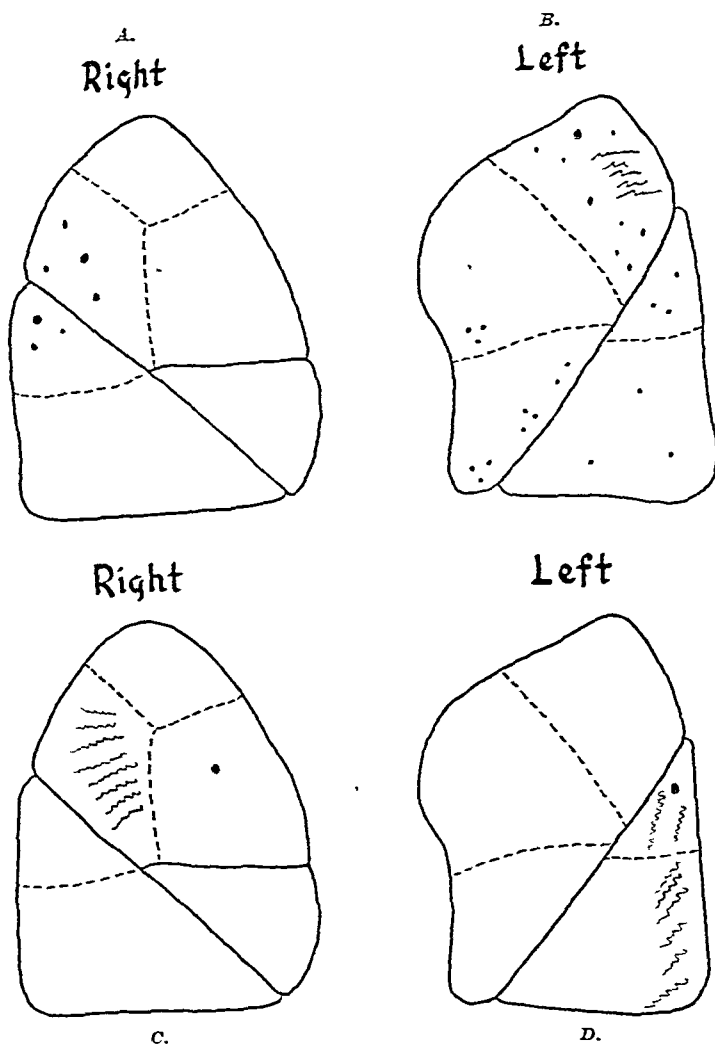
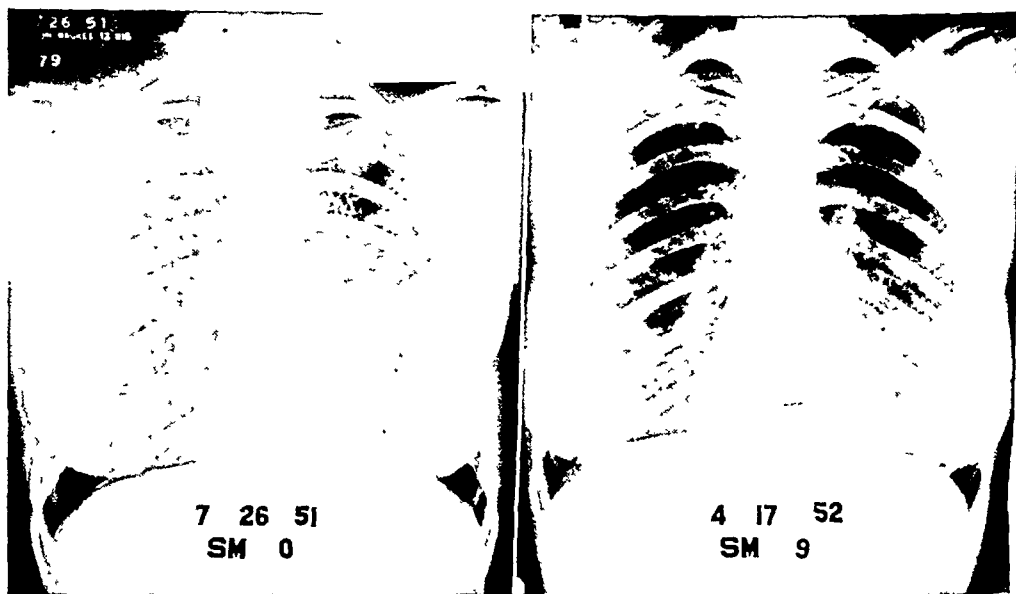


Fig. 2 (Cases 1 and 2).—A, Diagram of operative findings on right in Case 1. The posterior segment and a wedge from the superior segment were resected. The resected nodular lesions (shown in red) measured up to 1 cm. in diameter. Some lesions contained soft, and others hard, caseous material. B, Operative findings on left in Case 1. The apical-posterior segment was resected. The resected nodules (shown in red) contained hard to semiliquid caseous material. Culture of this material was positive on culture for tubercle bacilli. The wavy lines indicate fibrosis. None of the unresected nodules (shown in black) was over 2 mm. in diameter. C, Operative findings on right in Case 2. The posterior segment and wedge from the anterior segment were resected. Material from the 5 mm. nodule in the anterior segment was positive on smear and culture. D, Operative findings on the left in Case 2. Two wedges were resected. Material from the 5 mm. nodule was positive on smear but negative on culture.

We do know, however, that the tubercle bacilli recovered from the lesions of some of our patients did grow and did produce disease in guinea pigs. The eleven resected specimens which yielded tubercle bacilli which grew on culture or produced disease in a guinea pig were from eleven different patients; none of these patients had positive cultures or guinea pig inoculations of resected lesions from both lungs. These patients had original preoperative courses of chemotherapy varying in length from six to fifteen months.

The twelve operations in the last column (of Table VII) emphasize the difficulty in using roentgenographic findings as an indication of the presence or character of residual lesions (see Figs. 4 and 5). Four of the twelve operations were actually exploratory thoracotomies rather than resections as no palpable disease was found; the resected specimens from the other eight lungs



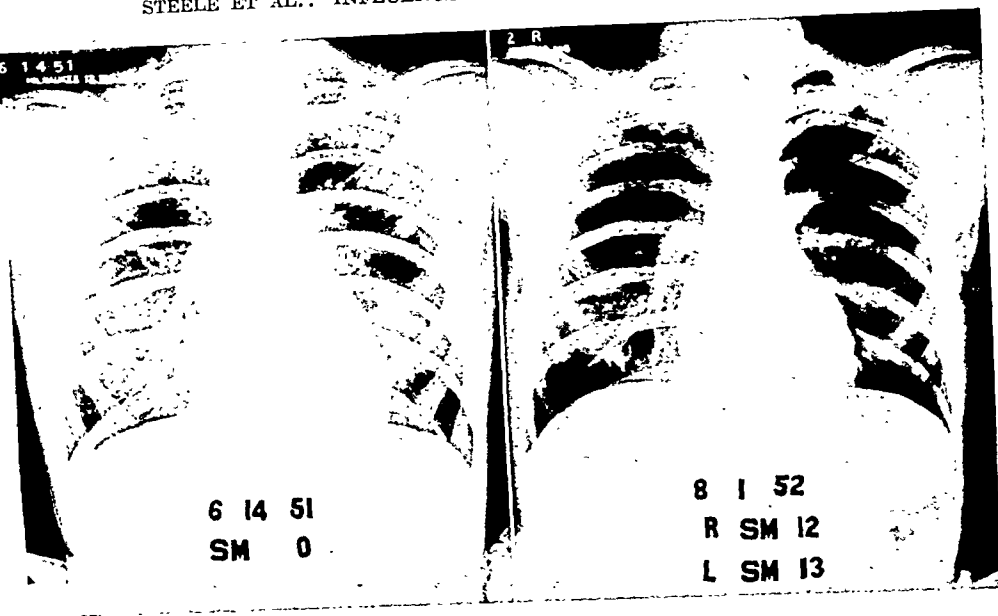
A.

B.

Fig. 3 (Case 2).—The patient was a 26-year-old white woman. A, Roentgenogram at start of chemotherapy. B, Roentgenogram after nine months of chemotherapy. Preoperative film. For operative findings see Fig. 2, C and D.

contained fibrous tissue only although in two of these, acid-fast bacilli were demonstrated in microscopic tissue sections. Ten patients are represented in these twelve "dry runs," two having had "dry runs" on both sides. Nine of these ten patients had had positive cultures of sputum or gastric contents just prior to chemotherapy; all lesions had shown definite roentgenologic improvement on chemotherapy. On reviewing the indications for thoracotomy in these twelve cases, we found only one which, in retrospect, we would not have explored again.

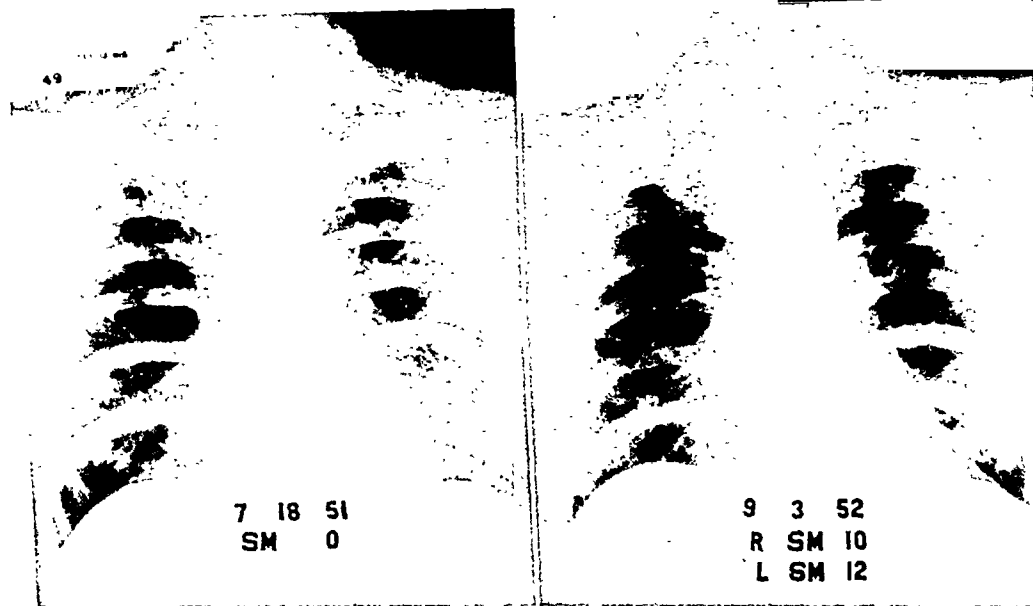
All palpable disease was resected from 91 of the 125 lungs and, as noted, four patients had no palpable disease. So much disease was present in 3 of the 125 lungs that resections were performed as biopsies only, to determine the character and bacteriology of a few of the lesions present.



A.

B.

FIG. 4 (Case 3).—The patient was a 46-year-old white woman. A, Roentgenogram at start of chemotherapy. B, Roentgenogram following twelve months of chemotherapy (preoperative film). Lesions resected on right contained fibrosis only with the exception on one 3 mm. caseous nodule. Lesions resected from left lung contained diffuse fibrosis only.



A.

B.

FIG. 5 (Case 4).—The patient was a 52-year-old white man. A, Roentgenogram at start of chemotherapy. B, Roentgenogram following ten months of chemotherapy (preoperative film). Lesions resected from right lung contained fibrosis only. Lesions from left lung contained one 3 mm. caseous nodule in addition to considerable fibrosis.

The distribution of our positive cultures and/or guinea pigs according to the streptomycin regimens used in preparation for resection is shown in Table VIII. The mixed regimens included combinations of the other two. All patients, of course, received daily PAS. The dose of streptomycin was 1 Gm. daily except in the case of the one child in the series. There is nothing particularly significant about the distribution of the positive cultures.

TABLE VIII. BACTERIOLOGY OF RESECTED LESIONS. ORIGINAL COURSES.
DISTRIBUTION OF RESECTIONS AND POSITIVE CULTURES ACCORDING TO SM REGIMENS

SM REGIMEN	4-8 MONTHS		8-24 MONTHS	
	RESECTIONS	CULTURE AND/OR GUINEA PIG POSITIVE	RESECTIONS	CULTURE AND/OR GUINEA PIG POSITIVE
Daily	16	1	33	3
2x week	6	0	39	3
Mixed	1	0	30	4

We were unable to find anything particularly characteristic about the pretreatment or preoperative roentgenograms of either the cases which subsequently yielded positive cultures (or guinea pigs) of their lesions or the cases which had no palpable disease or predominately fibrotic disease. The roentgenograms and operative findings of two representative cases from the former group are illustrated in Figs. 1 to 3; the roentgenograms of two patients from the latter group will be found in Figs. 4 and 5.

In all of our patients whose lesions were resected following preparation with long-term chemotherapy we have continued chemotherapy for an arbitrary postoperative period of three months. Patients having significant unresected disease have had longer postoperative courses. Recently, because of late recurrence of disease in two patients whose lesions were positive on culture, we have decided to give patients who have positive cultures of their lesions additional postoperative chemotherapy.

As indicated above, our follow-up period is too short to be significant. Only thirty patients prepared with long-term chemotherapy for resection have been followed for one year. However, four patients followed for less than a year have recurrent disease. Two of these have had positive cultures of their secretions only while the other two have also had roentgenographic recurrences.

SUMMARY

Pulmonary resections were performed on 112 patients whose tuberculous pulmonary lesions had responded favorably to long-term courses of streptomycin and PAS.

Bacteriologic examinations were carried out on all resected specimens. The final evaluation of this resection program will require a long follow-up period. Our present indications for collapse therapy are discussed.

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DISCUSSION

COLONEL JAMES H. FORSEE, Denver.—It may be of interest to report briefly certain follow-up data regarding patients treated at Fitzsimons Hospital during the period from January, 1947, to approximately one year ago.

Three hundred sixty-nine patients received extirpative surgery. An interesting fact is that the disease process in this group of patients, preoperatively in 60 per cent, whether cavitary or noncavitary, was limited to an area involving only one lobe and limited in extent to an area no greater than that above the level of the second costochondral junction. This is the classification of minimal tuberculosis, but these patients are not minimal tuberculosis; 30 per cent had cavitary lesions.

The surgical procedures employed in this 60 per cent, or 221 patients, was lobectomy in 52 per cent, wedge resection in 31 per cent, and segmental resection in 17 per cent. The follow-up data approximately one year to more than five years as available in 97.3 per cent. Of these patients 93 per cent are living and well; three patients, or slightly over 1 per cent, are dead (none due to tuberculosis); five patients, or 2.3 per cent, had reactivation of the disease occurring at intervals of four to eleven months postoperatively. The reactivation of previously unrecognized foci occurred on the side of the resection in three patients, and on the contralateral side in one patient. Bacteriologic relapse occurred in one instance without evidence of reactivation or new pulmonary lesions. In three of these five, the patient had cavitary disease. Glandular tuberculosis occurred in two patients or .9 per cent; one occurred four years after pulmonary resection. The other was a reactivation of previously existing cervical adenitis four years after operation. At this time 57 per cent of these patients are gainfully employed, part or full time; 36 per cent are well but have not returned to work. Seventy-one of the 221 patients have been operated on since 1951.

To us, these facts reveal that more and more patients with less and less pulmonary tuberculosis are being successfully treated by surgery. It seems reasonable to anticipate that this is the trend in the surgical management of pulmonary tuberculosis since the advent of the antituberculosis drugs. And it seems reasonable to predict that, if the disease is detected early, if proper therapy is instituted and carried to its completion, more than 90 per cent of

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patients with uncomplicated pulmonary tuberculosis will recover and return to active gainful occupation—a great tribute to many of those in this audience today who have devoted so much of their lives to the treatment of pulmonary tuberculosis

DR E J O'BRIEN, Detroit—I have been very much interested in Dr. Steele's paper, but it was very difficult for me to follow him. He spoke constantly of long term treatment, and yet slide after slide went on the screen where the long term treatment was shown as from four to eight months. That is not long term treatment. He also questions the value of thoracoplasty after long term treatment, though the cavities are still open. Many of the rest of us believe that cavities not closed after six months will not close under this regimen alone, and that thoracoplasty or some other collapse measure should be used to assist in closure, unless resection seems indicated.

He mentions producing disease in guinea pigs from cultures or caseous material after so called long term treatment. I believe I have read about all the literature that has been published on the subject, and I have yet to find a report from anybody who has produced disease in guinea pigs after what is really continuous long term treatment. I looked over Dr. Steele's figures yesterday and he has not produced disease in guinea pigs after sixteen months of chemotherapy had been given.

DR STEELE (Closing)—The matter of what should be called long term therapy is very arbitrary. We arbitrarily selected four months as a minimum for our long term cases. However, I would like to remind you that we had 102 resections on patients receiving original courses of streptomycin and PAS of eight months or more, and that the viable, pathogenic bacilli which we recovered were from eleven patients receiving from six to fifteen months of original courses of long term chemotherapy.

SEGMENTAL RESECTION FOR PULMONARY TUBERCULOSIS (300 CASES)

J. MAXWELL CHAMBERLAIN, M.D., CAPTAIN CLIFFORD F. STOREY, MEDICAL CORPS,
UNITED STATES NAVY, ROBERT KLOPSTOCK, M.D., AND
CHARLES F. DANIELS, M.D. (BY INVITATION)
NEW YORK, N. Y.

INTRODUCTION

SEGMENTAL resection in the surgical management of pulmonary tuberculosis is now an established and accepted procedure.¹⁻²⁸ It can be used in minimal, moderate, and far-advanced cases of pulmonary tuberculosis provided the major offending focus is limited to one or two segments of the lobe. The rate of sputum conversion is high and with experience the morbidity and mortality rates are low. The operation is moderately intricate and demands great postoperative vigilance, but it avoids prolonged hospitalization and, by corollary, reduces the task of rehabilitation. Its greatest virtue, of course, is its preservation of pulmonary function as was intended by its originator, Dr. E. D. Churchill,²⁹ and other early workers.³⁰⁻³³

BASIC PATHOLOGY

Tuberculosis usually begins as a "patch" of indolent pneumonia confined to the upper and posterior segments of the lobes as reported by Medlar and others.³⁴⁻³⁶ Less frequently it may involve a lobe or the entire lung but regardless of its dimensions it begins as a pneumonia.

The patch of pneumonia may take three courses: (1) resolution, (2) fibrosis, or (3) caseation necrosis. If resolution of the exudative element occurs, the alveolar walls remain intact, no function is lost, and ultimately all evidence of the disease disappears from the chest film. If fibrosis occurs the area is replaced by "scar" tissue (the productive reaction), alveolar function is lost, and the x-ray film always reveals the site of the insult. In other instances small "patches" of pneumonia coalesce to form a large conglomerate area. If the vascular nutrition to the center of this area is lost, caseation necrosis occurs and the alveolar architecture is destroyed. Usually one or more small bronchi communicate with the necrotic area, and should liquefaction of this caseous material occur the area "shells out" to form a cavity.

In every lesion probably all three factors are at work. There is some resolution, some fibrosis, and some caseation necrosis. It is the necrotic focus, and especially the size of this focus, that threatens the patient's future welfare. Through liquefaction of this necrotic area bronchial dissemination of the disease may occur. Segmental or subsegmental resection performed at the proper time is designed to avoid such spreads.

The opinions or assertions expressed in this paper are private ones of the authors and are not to be construed to be official or to reflect the views of the Navy Department or the Naval Service at large.

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BASIC PHYSIOPATHOLOGY

The functional advantages of leaving behind only one of three segments of a lobe was at first debatable. It was reasoned, however, that as a functional unit it contributed its bit to the total function and as a "filler" it prevented excessive distention of the residual lung components and in this way preserved their function. We now know by actual bronchspirometric measurement performed on a series of these patients before and after segmental resection that little or no function is lost and in some cases it seems to be actually improved. One of us (C. F. S.) will report on this functional aspect at a later date.

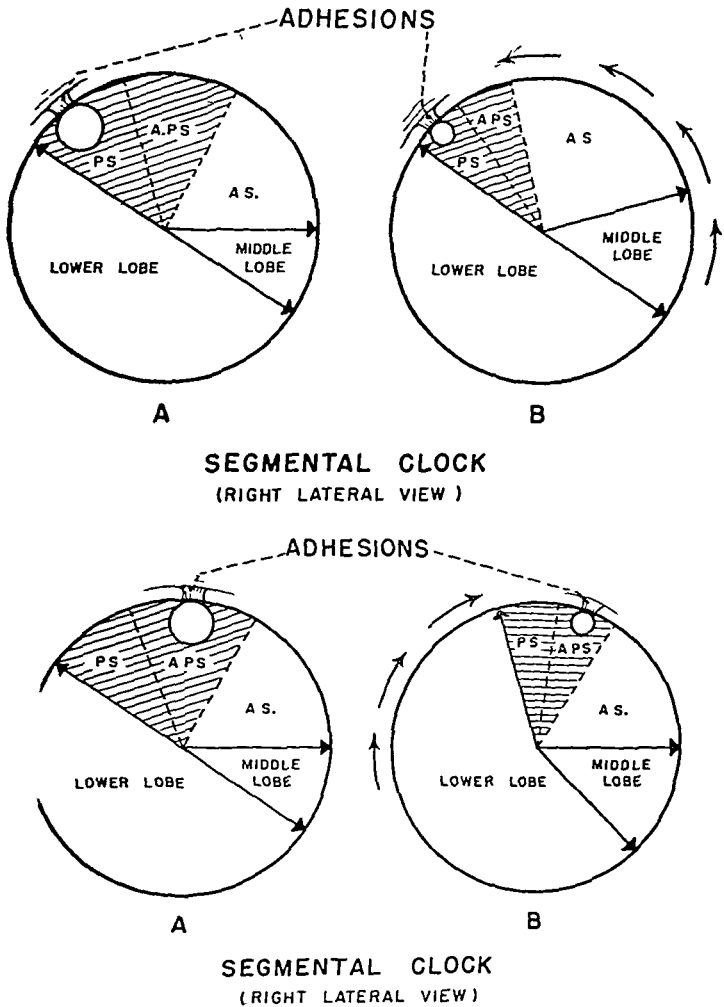


Fig. 1.

The residual segments are usually larger than normal, and the presence of adhesions may determine which segments will enlarge to compensate for the healing and contraction in the diseased segments. For example, ad-

hesions between the right posterior segment and the chest wall will not permit enlargement and upward movement of the lower lobe as healing and contraction occur in the apical and posterior segments. However, with the hilum of the lung as an axis, a counterclockwise enlargement of the anterior segment and the middle lobe is often observed (Fig. 1). On the other hand, if adhesions exist between the right apical segment and the thoracic vault as healing and contraction occur the lower lobe enlarges and rises high in the pleural cavity. In such cases there is less demand for the anterior segment and middle lobe to enlarge. The segments in which the enlargement is greatest are in cases free of adhesions. Conversely, an obliterative pleuritis seems to prevent not only the contraction of the diseased segments, but any significant enlargement of the healthy components as well.

INDICATIONS

The main indication for segmental resection is the necrotic lesion. Necrotic lesions may be small, medium, or large and still confined to one or two segments of a lobe. Not only is the size of the necrotic focus important, but also its duration and especially the amount of associated exudative or pneumonic disease.

The duration of the lesion is significant because it is difficult in the chest film to distinguish the boundaries between shadows due to exudative, fibrotic, or necrotic disease. It may be reasoned, though not without an element of doubt, that if the lesion has been present in serial x-ray films for some time, it is predominantly a fibrocaseous lesion. In other words, the acute exudative or pneumonic elements have probably resolved. If, however, the shadow is being viewed for the first time this assumption may be inaccurate.

The size of the necrotic focus is important because the small foci are drained in most instances by small bronchi and the large ones are drained by large bronchi. It seems reasonable to suppose that the caseous material undergoing liquefaction will drain more easily through a large bronchus than through a small one, and perhaps it follows that it "spreads" more easily as well. These points require further proof.

Exudative disease can be expected to respond to conservative management and antibiotic therapy permitting the dimensions of the operative procedure to be reduced. Emergency operations have been successfully performed in the presence of acute tuberculous pneumonia, because of hemorrhage, cavity rupture, and extensive pneumonic "spreads,"¹³⁷ but in general, major thoracic procedures, including thoracoplasty, should not be done in the presence of significant exudative or pneumonic disease.

The ideal indication for segmental resection is the fibrocaseous lesion with or without a cavity and devoid of an exudative element. The focus should be of such size and duration that mature medical opinion is doubtful of the patient's future security.

PREOPERATIVE STUDY AND PREPARATION

Laminography, especially the lateral sections, introduced by one of us (R. K.),³ gives an extremely valuable preview to the thoracotomy. The phrase

"bloodless thoracotomy" applied to laminography seems justifiable to those accustomed to its use. Perhaps no other preoperative study is more helpful to the surgeon.^{2, 38, 39} The exact location of the disease, and especially the appearance of the segments to be left behind, may be learned from these studies. As experience in the use of laminography increases, it is rare for the surgeon to perform a lobectomy when a segmental resection was intended. If a segmental resection is contemplated, a rib is usually not removed, the chest being entered through an intercostal incision since a tailoring surgical procedure after a segmental resection is usually unnecessary.

The specific antibiotics are given for variable lengths of time prior to the operation, but always until the exudative element surrounding the fibrocaseous focus is thought to be absent. Other preoperative studies are similar to those which should precede any major surgical operation.

TECHNIQUE—OPERATION

Prior to operation as a result of lateral laminography the surgeon is reasonably aware of the pathology and its dimensions. The segments to be removed have been decided upon and the bronchi to these segments are immediately isolated and clamped before unnecessary manipulation or mobilization of the lung. (There are anatomic exceptions to this plan.) Gentle palpation of the pathologic lesion usually confirms the decision reached through the use of laminography. After the segmental bronchi have been clamped and divided, the lobe is then mobilized with impunity since secretions can no longer be expressed into the bronchial tree. Occasionally after palpation our interpretation of the laminographs proves inaccurate and it is necessary to remove an additional segment or subsegment.

The arteries to the segment are then isolated, ligated, and divided. Preservation of the intersegmental veins is desirable when only one segment is removed, but when two segments are removed it is necessary to remove the intersegmental vein with the specimen. The intersegmental plane is then developed by gentle traction and dissection as described by Clagett.³² Bleeding from the raw area is meticulously controlled. No effort is made to cover the raw area with pleura as was previously described⁴; any attempt to close it will only distort the segment and interfere with its ability to "breathe." Furthermore, were the raw area to be closed, in all probability the sutures would cut out in the next few days during deep breathing or coughing. The bronchus is then reamputated and closed with interrupted silk sutures. Pleuralization of the bronchial stump is not always done. Usually the residual segment or adjacent lobe seals the bronchus upon complete re-expansion. Two tubes are left in for drainage and re-expansion. One tube is anterolateral and fixed with a suture to the pleura of the thoracic vault. The other tube is low and in a posterolateral position. The wound is closed in anatomic layers and a small narrow dressing is applied in order to allow adequate clinical examination of the chest during the immediate postoperative period. The large firm

dressings physiologically simulates the so-called captive lung mechanism. Unilateral tidal loss is significant.⁴⁰ The two tubes are connected to a "Y" tube and placed upon active suction (see Discussion).

POSTOPERATIVE REGIME

At the completion of the hilar dissection the residual segments are inflated, the intercostal tubes are placed, and intrapleural suction is established simultaneously with wound closure. Approximately 200 c.c. of saline solution are left in the pleural cavity to dilute the small amount of blood which gravitates to the dependent parts of the hemithorax during wound closure. The dilution of blood by the saline solution prevents clot formation and helps to insure patency of the tubes during the early postoperative period. Most of the saline solution is immediately removed by the suction system as wound closure is completed. A compact portable suction pump is used to maintain the desired intrapleural pressure during transportation from the operating room. This maneuver, though not essential, is an additional precaution to insure immediate and complete re-expansion of the residual lung components.

The patient's position in bed is at first on the side of the operation. Later he is turned to his back and for effective coughing he is allowed to assume the sitting position. Young people with muscular diaphragms will tolerate slight elevation of the foot of the bed. This allows the fluid to gravitate to the thoracic vault and keeps the costophrenic angle sharp. The fluid is then removed through the upper tube and the pleural reaction is confined mainly to the thoracic vault. "Pleurisy" which binds or fixes the diaphragm may significantly influence function. Pleural reaction in the thoracic vault is of little functional significance.

Intrapleural suction is usually set at a minus 15 to 25 cm. of water. Pressures at a minus 5 to 10 cm. of water are basal-physiologic. Intrapleural suction is usually set at a minus 15 to 25 cm. of water, pressures at a minus 5 to 10 cm. of water are basal-physiologic. End-operative studies on the bronchspirometric contribution of the individual lung have revealed that pleural suction in the range minus 5 to minus 16 in fact results in a control subtidal, ipsilateral ventilation. Maximum tidal volume occurs with negative pressures in the range of minus 18 to minus 20. It should be noted that Lindskog found experimentally that reinflation via collateral ventilation requires a gradient of some 16 cm. of water.

If the segments are to remain inflated the bronchi and bronchioles must not become occluded by blood or secretions. Clots of blood in the small bronchioles may be propagated to larger and larger divisions to produce a segmental atelectasis. On the other hand, if good air flow is maintained up through the bronchioles and out through the small alveolar leaks, secretions do not collect to account for subsegmental or segmental atelectasis. In our experience active suction does not prolong alveolar leaking. In the majority of cases the tubes can be removed in forty-eight to seventy-two hours, but tubes are never removed at night. It seems preferable to remove them in the morning when a full complement of nurses and doctors is available, should a pneumothorax develop. A roentgenogram is taken a few hours after the

tubes have been removed with a portable chest x-ray machine to determine the degree of lung expansion. A sterile trocar, cannula, and catheter are always available and suction is re-established immediately should a "late leak" develop. Complete and early re-expansion seems essential in the prevention of an empyema or bronchopleural fistula.

Patent airways, large and small, are essential to successful re-expansion. Ciliary action, bronchial peristalsis (elongation and foreshortening of bronchus during the respiratory cycle), and cough are the patient's protection against spreads and atelectasis. The patient is urged by the nurse to take thirty deep breaths every half hour during his waking hours. Furthermore, he is encouraged to help turn himself in bed frequently. This exercise promotes deep breathing. However, intratracheal suction each morning and night during the first forty-eight hours is perhaps the most important postoperative assistance the patient can be given. Its disagreeable aspects, if nothing else, assures patient cooperation throughout the day whenever he is urged to cough by the nurse in attendance.

Pain is caused by the incision, muscle spasm, the divided ribs, and the pleura. Little can be done about the incisional pain. The muscle spasm can be reduced by frequent passive and active shoulder girdle exercises. Fixation of the divided ribs during closure will prevent pain arising from the fracture site, but pain from the pleura is more difficult to control. The parietal pleura is very sensitive and the visceral surface of the residual segments is altered: (1) by operative manipulation (gauze abdominal pads, sponges, etc.); and (2) by the precipitation of fibrin as a result of the mild but ever present hemothorax. The movements of these residual lung components against the parietal pleura, plus the pleural irritation of the drainage tubes, are probably responsible for most of the pain. This theory is supported further by the fact that patients after a pneumonectomy have much less pain than patients after a lobectomy or a segmental resection.

Since patent airways are essential to re-expansion and perhaps life, and since coughing and deep breathing are painful, it follows that the control of pain is extremely important. Narcotics, not sedatives, will control pain. Their frequent use in moderate dosage is encouraged. The use of narcotics in chest disease earned its bad reputation in the primordial stages of our learning. Vigilant nursing and a regimented postoperative plan will not allow the patient to slip into narcotic coma and drown in his own secretions.

Specific antibiotics are used routinely after operation. They are continued for various lengths of time as determined by the attending physician, usually for not less than three months. The nonspecific antibiotics are used one day before surgery, at operation, and for the first week after surgery. Nontuberculous empyema and wound infections have played no significant role in this series.

Transfusions are used during and after operations to maintain blood volume. Usually 1,500 to 2,000 c.c. of blood is given each patient.

Ambulation is permitted during the first two weeks after operation to encourage costal and diaphragmatic breathing. Early restricted activity may

lead to high fixation of the diaphragm and cause a corresponding decrease in respiratory function. The patient returns to bed after two weeks and remains there usually for three months except for lavatory privileges. Activity is then increased again.

The use of oxygen in segmental resection is important in the older patient, but it is rarely necessary in the young patient with good coronary circulation. The temporary costal and diaphragmatic restriction after operation creates a "shunt" and the oxygen saturation of the blood does not return to normal for a variable number of days. In the older patients the coronary circulation is an unknown factor. In this group the generous and prolonged use of nasal oxygen is encouraged. Nasal oxygen seems preferable since these patients require a great deal of nursing attention which is difficult to administer if a tent is used.

"Diet as tolerated" is not that simple. Abdominal distention with elevation of the diaphragm is a frequent postoperative complication which may embarrass respiration. Clear liquids are given the first day supplemented by intravenous fluids if necessary. On the second day nourishing liquids, soups, custards, etc., are usually tolerated. However, an unexplained elevation in pulse rate in a patient who is not vomiting may be an indication for gastric decompression. In muscular young men gastric distention is not as obvious as in atonic women or older men. Acute gastric distention, therefore, should be suspected in every muscular young man whose fluid intake is adequate, but who remains thirsty, runs a rapid unexplained pulse, and is not vomiting.

An upright posteroanterior and lateral x-ray film is taken on the first postoperative day with a portable machine. A second is taken on the day the tubes are removed (usually the second or third postoperative day). A third is taken on the fourth or fifth postoperative day. After that the patient is well enough to stand for fluoroscopy at frequent and regular intervals. Such vigilance is necessary since "late leaks" seem to occur in about 5 to 10 per cent of the patients, and immediate intercostal intubation will avoid the complications associated with the unexpanded lung. On several occasions we have had to intubate a patient more than twice. A late leak developed in one patient on the fourteenth postoperative day, one day before discharge. In another patient it did not develop until the forty-first postoperative day. The "late leak" is considered a minor complication because these patients need not return to the operating room for intubation and it is extremely rare for the "late leak" to progress and cause a major complication, such as empyema or bronchial fistula.

DISCUSSION

Pulmonary tuberculosis is usually bilateral though not necessarily bilaterally active. The advocates of segmental resection are the first to admit that only the major offending focus or foci are removed by this procedure. Foci are almost always present in the opposite lung or in the residual lung components on the side of the operation. These foci are also present in patients successfully treated by other forms of therapy such as bed rest, pneumothorax,

or thoracoplasty. Removal of *all* of them is technically impossible and probably unnecessary. The decision to remove other foci is dependent upon size and location.

The actual size of the hazardous lesion is difficult to estimate in centimeters. Usually a large lesion is more hazardous than a small one, but on the other hand a small lesion in a patient without resistance can be more hazardous than a much larger one in a patient who seems "unable to handle his disease." Furthermore, it is noted by those in the field of experimental research, by the pathologist and by the clinician, that lesions in the anterior and dependent segments of a lobe are less hazardous than those in the posterior and apical segments. Cavities located anteriorly are recalled only because they are exceptions to the rule or because they began in the apical-posterior segments and extended into the anterior and dependent areas. A lesion requiring resection in the superior segment⁶ of the lower lobe may safely remain in the tip of the lingula. To molest the various lobes by attempting to remove locally all foci, large and small, without regard for location ignores this basic information and subjects the patient to unnecessary morbidity and perhaps mortality. This belief is based not only upon our recent and short experience with segmental resection, but upon a comparatively long experience with the thoracoplasty procedure. Though the therapy has changed the location of tuberculosis is the same. Therefore, there must have been foci anteriorly in the days when the thoracoplasty was our most popular form of surgical therapy. Yet our failures were not usually due to the "breakdown" of lesions anteriorly where the collapse was least, but due to unclosed cavities posteriorly where the collapse was greatest. It is not implied, however, that tuberculosis located anteriorly should not be respected.

Overdistention of the residual segments after segmental resection is less than after lobectomy and pneumonectomy. Physiologically, respiratory function is inversely proportional to the degree of emphysema caused by overdistention. Lung elasticity is variable,⁴⁰ and in all patients with tuberculosis there exists a variable amount of emphysema. Laennec, without a microscope, described focal emphysema surrounding every healed and contracted lesion. The physiologic effects of overdistention are much more noticeable in the older patient with horizontal ribs and a thick anteroposterior diameter than in the slender young patient with oblique ribs and a comparatively narrow chest. There must be a limit to the amount of distention a lung can tolerate before actual alveolar wall destruction occurs. The speed and duration of overdistention are also factors. Tuberculosis is an indolent disease which heals slowly. As healing and contraction of the diseased segments occur, a slow compensatory enlargement of the healthy parenchyma takes place. The undesirable aspects of suddenly demanding a single lobe to fill one chest after a lobectomy has led us to believe that a small tailoring procedure should be done simultaneously.

Overdistention may or may not be responsible for the "breakdown" or reactivation of disease in the residual segments. A point less debatable is the fact that should a breakdown occur the emphysematous patient does poorly

with tuberculosis and usually to an extent inversely proportional to the amount of emphysema. It is thought that one of the factors responsible for such a response in the emphysematous patient is interference with the cleansing mechanism. The patient's protection against "spreads" is enhanced by an effective cleansing mechanism (1) ciliary action, (2) bronchial peristalsis, and (3) cough. Bronchial peristalsis consists not only of changes in the diameter of the bronchial lumen but changes as well in the length of the bronchus during inspiration and expiration. In the overdistended lobe the bronchus is not only distorted by its new position but is relatively fixed and permanently elongated. The amount of foreshortening is reduced. Furthermore, the amount of residual or "stagnant" air is increased and the amount of tidal or "movable" air is reduced. The effective cough is dependent upon movable air. Therefore, not only is overdistention undesirable from a physiologic viewpoint but from a pathologic one as well.

Obliteration of the dead space simultaneous with the segmental resection is done to avoid complications. When an obliterative pleuritis is present the adhesions may prevent the compensatory enlargement of the healthy components and a rather large space remains after the resection of two or more segments. This space may be obliterated in two ways: (1) by a small tailoring thoracoplasty (costectomy), and (2) by extraperiosteal plombage without rib removal.

The small tailoring costectomy removes short segments of second, third, and fourth ribs posteriorly. The first rib may or may not be included. If not, the periosteum on its lower surface is mobilized with the others. The risk of the additional surgery and the paradoxical chest seems justifiable.

The extraperiosteal plombage reduces scoliosis and the amount of paradox. The procedure is the same as described except that the periosteum on the outer surface of the ribs is preserved, the ribs are not removed, and the extraperiosteal "plomb" may consist of (1) the patient's own subscapular collection of blood, (2) many sheets of Gelfoam, or (3) a plastic sponge encased in a polyethylene bag.

In obliterative pleuritis mobilization of the lower and middle lobes is not done when the preoperative fluoroscopy reveals good movement of the diaphragm. Should the lobes be mobilized the diaphragm usually rises to follow their ascent into the thoracic vault. The division of the many adhesions provokes oozing and "sweating" of blood which may result in a hemothorax to bind and restrict diaphragmatic movement. The functional loss from a small tailoring surgical procedure in the thoracic vault is less than that due to diaphragmatic fixation.

STATISTICAL ANALYSIS

A series of 300 consecutive patients who had segmental resection for pulmonary tuberculosis has been followed for one to five years. At the present time 93.7 per cent are living and well, 3.3 per cent living with disease, and 3 per cent are dead (Table I).

TABLE I. DEATHS. 9 (3%)

<i>Primary Operative</i> —3 (1%)	
W. M.	2nd P.O. † Coronary occlusion
G. A.	4th P.O. Contralateral pneumonia
W. F.	12th P.O. Lower nephron nephrosis
<i>Secondary Operative for Bronchopleural fistula</i> —4 (1.3%)	
<i>Other</i> —2 (0.7%)	
A. M.	9 mo. P.O. of Bronchopleural fistula
G. S.	2 yr. P.O. of alcoholism

The type of operative procedure was as follows: 210 (70 per cent) had segmental resection only; 32 (10.7 per cent) had lobectomy plus segmental resection; 31 (7 per cent) had bilobar segmental resection; 35 (11.7 per cent) had local excisions only; 2 (0.7 per cent) had right upper and middle lobectomies combined with resection of the superior segment of the right lower lobe. The significant major complications were bronchopleural fistula, tuberculous emphysema, and spread (Table II). In addition one patient had hemorrhage from a small pulmonary vessel and required reopening of the wound for ligation. Another patient required decortication twenty-four days after operation to obtain complete re-expansion of the lung.

TABLE II. 300 SEGMENTAL RESECTIONS. FOLLOWED 1 TO 5 YEARS

Living and well	281 (93.7%)
Living with disease	10 (3.3%)
Dead	9 (3.0%)

There were nine deaths (Table III). Three patients died as a result of the operation. Patient W. A., who was apparently progressing satisfactorily, died suddenly on the second postoperative day presumably from coronary artery disease. Autopsy did not definitely disclose cause of death. Patient G. A. did very well for two days after operation. X-ray review at that time showed clear lung fields, but late in the afternoon of the second day the patient began to show signs of contralateral pneumonia. Death occurred two days later. Post-mortem examination revealed the contralateral lung to be heavy, gelatinous, and essentially free of purulent secretions. Four patients died as a result of secondary operations to correct bronchopleural fistula and tuberculous empyema: M. P. had hemorrhage from a subclavian artery which was involved in the tuberculous empyema. Control was impossible and he died two days later. D. G. died of an anesthetic accident after pneumonectomy had been completed for bronchopleural fistula. L. G. died nine days after

TABLE III. MAJOR COMPLICATIONS

	NO.	DEAD	PERSISTENT	CONTROLLED
Bronchopleural fistula	16 (5.3%)	5 (1.7%)		11 (3.7%)
Empyema	13 (4.3%)	5 (2.7%)	1 (0.3%)	7 (2.3%)
Spread	9 (3%)	5 (1.7%)	1 (0.3%)	3 (1%)

thoracoplasty and partial resection of the right lower lobe to correct bronchopleural fistula. The fistula was controlled but the limited functioning lung tissue was not sufficient to support the patient. F. W. died after multiple procedures to correct fistula which persisted. A. M. died nine months postoperatively with a persistent bronchopleural fistula. An acute bronchitis was the contributing factor to the final episode. G. S. had a segmental resection for tuberculosis and was well with negative culture and clear x-ray films, but he was found dead in bed apparently due to alcoholism two years after operation.

TABLE IV. EXACERBATIONS. 18 (6%)

Resolved	
a. Antibiotics only	5 (1.7%)
b. Additional surgery	6 (2%)
Persistent	7 (2.3%)
Total	18 (6%)

There have been eighteen exacerbations in the entire series (Table IV). Eleven have resolved with further surgery or antibiotic therapy; seven persist. About two-thirds of these occurred immediately or within the first six months and the remainder at scattered later intervals after operation. The late exacerbations have not represented a serious problem in these patients.

Eight patients had planned bilateral resection and two required unplanned contralateral resection for pre-existing disease.

SUMMARY

1. The basic pathology of tuberculosis is an indolent pneumonia which may (1) resolve, (2) fibrose, or (3) caseate. Usually all three elements are present in every lesion.

2. The basic physiology is not significantly changed by segmental resection, because only the diseased components are removed and compensatory mechanisms have already been effected.

3. The indication for segmental or subsegmental resection is a fibrocaseous lesion with or without cavitation confined to one or two segments of a lobe, but still large enough that mature clinical opinion is doubtful of the patient's future security.

4. The preoperative preparation is the same as for any major operation with special attention to laminography and especially the lateral laminography.

5. An anatomic segmental resection is done for moderate and far-advanced lesions. In minimal lesions a wedge resection or local enucleation is possible. Subsegmental resections may also be done anatomically.

6. Postoperative care must be vigilant. Patent airways (intratracheal suction), the control of pain, the use of antibiotics, the obliteration of dead space by complete re-expansion of the lung using active suction and checked by frequent postoperative x-ray examinations are important to a successful result.

7. Tuberculosis is usually bilateral though not bilaterally active. Only the major active focus is removed by segmental resection. The importance of other foci is dependent upon the size and location. Anterior foci are less hazardous than those posteriorly.

8. The problem of overdistention is not great after segmental resection, but obliteration of the dead space is essential to success. Occasionally a periosteal plombage procedure without resection of the ribs is done in deference to this principle.

9. In obliterative pleuritis mobilization of the lung is not done when the preoperative fluoroscopy reveals good diaphragmatic movement. The functional loss is less if a small tailoring surgical procedure is done in the thoracic vault.

These patients were operated upon by us or members of hospital staffs trained by us in order to standardize the technique. Many cases were done on Dr. Berry's service at Bellevue Hospital, Dr. Miscall's service at Triboro Hospital, and the rest were done at St. Albans Naval Hospital, Halloran Veterans Administration Hospital, Nassau County Sanatorium, Brooklyn Thoracic Hospital, and Doctors Hospital. We are grateful to the medical staffs in these hospitals who were mainly responsible for the selection of these cases and for their management and rehabilitation after surgery.

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DISCUSSION

DR. AARON HIMMELSTEIN, New York.—I should like to review the early complications as compiled by Dr. Vaughan and myself from the records of the chest surgical service at Bellevue Hospital in the resections for tuberculosis from October, 1949, through December, 1952. Some of the segmental resections in that group are in Dr. Chamberlain's group, but they also include some of his cases done after the closing date of his series. Almost all these operations were done by the resident surgeons supervised by a member of the staff.

There are 139 lobectomies or pneumonectomies—101 lobectomies and 38 pneumonectomies. In this group there were eight fistulas, two in the pneumonectomy group, the rest in the lobectomy group. Each fistula usually gave us a problem of spread, and the deaths were in large measure in this group. We had ten spreads and six deaths. There were ninety-four segmentals, sixty-four of which were just segments, fifteen were just wedges, one was a lobe and a wedge, and fourteen were lobe and segments.

We have been more rigid in our criteria for selecting a case as having developed a fistula than Dr. Chamberlain was; we have included the group that he called leaks. However, I think there is a distinct difference between them clinically. Leaks that come from the surface of lung that has been opened up, apparently do not present the oppor-

tunity for gross microbial contamination of the pleural space that is present with a leak at the stump of a bronchus. They do not go on frequently to develop empyema. Clinically I think that has been true and I agree with what Dr. Chamberlain said about these leaks. However, we have included all of them as fistulas, and we have twelve in the group of ninety-four segmentals. Four of those were in the group of lobes and segments and six were in the segments alone. There were two deaths in this group; one was due to a proved pulmonary embolus and the second we presumed was a pulmonary embolus although we have no proof by autopsy. Both were in the early postoperative period.

DR. NORMAN WILSON, Brookline.—I should like to congratulate Dr. Chamberlain and his co-workers, not only for their excellent results but to pay tribute to them as pioneers in the use of segmental resection in the treatment of tuberculosis. We all owe a great debt to them. I should like to tell you of some of the lessons we have learned from studying a large series of resections throughout the years, because I think that even though this is a very successful form of treatment in selected cases of tuberculosis, if that selection is violated, the amount of trouble encountered will be very great. To show what I mean, if we separate in our follow-up series those cases which represent primary surgical treatment early in the course of their disease with intelligent timing with regard to drug treatment, we find that 94 per cent of the segmental resections are well in the follow-up study. But if we take those "second-hand" patients who have had other forms of treatment, who have unexpandable lungs, who have had numerous spreads while lying in bed with unsuccessful thoracoplasties for many years, before segmental resection is used (often times as a salvage procedure) then we find that only 50 per cent in the follow-up study are well.

It would be of interest to me to know what percentage of Dr. Chamberlain's cases are primary and what percentage are secondary. You will note that two of the series of cases discussed here this morning represented almost 100 per cent primary treatment cases and this is reflected in the good results reported in their follow-up studies.

We have tried to develop basic fundamental concepts in approaching this problem. In our experience the fundamental requirements which must be observed when using segmental reaction, if good results are to be anticipated, are as follows: (1) An adequate pulmonary reserve, (2) the offending lesion to be resected is within the unit of lung which one intends to resect be it lobe, segment, or lung, (3) that the surgical approach be the primary approach to the problem, (4) that rest and medical treatment have been used to adequately prepare the patient for this procedure.

If these fundamental concepts are adhered to, the results will be good. If they are violated, results will be bad. You will note how carefully Dr. Chamberlain has used lateral laminography to rule out other offending lesions, and I am sure he considers this to be very important and I agree with him on that point. I think it is extremely important not to translate the results of segmental resection representing such ideally selected cases into the experience of those of you who will have to tackle "second-hand" cases, because the problems are entirely different.

DR. E. J. O'BRIEN, Detroit.—It is not easy to take any exception to such a splendid presentation. You have just heard of seven deaths in a series of 300, which is certainly very small. It is a very difficult paper to discuss because Dr. Chamberlain did not put his neck out very far. He showed us a few roentgenograms of patients who were operated upon, but what amount of disease the other patients in the group of 300 had, he does not say. What is bothering me is that his five-year résumé began long before the use of long-term chemotherapy. I cannot understand it. I know what an excellent surgeon Dr. Chamberlain is and I certainly do not question his results, but it rather adds to the chaos I mentioned this morning. I cannot quite visualize how segmental resections can be used in extensive pulmonary lesions without long-term chemotherapy and have such results as he quotes, and I cannot understand either how he differentiates spreads from reactivations. The mere fact that the preoperative film did not show these lesions does not mean a thing to me, because there are many lesions found at the operating table that were not suspected

preoperatively. And it is in these areas that we have frequently seen reactivation. Seven deaths are not very many, but we do not know that any of these were necessary. I showed 403 cases this morning without any treatment other than chemotherapy, and there were no deaths; just five reactivations and two of those had no change in the x-ray appearance. They were called reactivations because of one or two positive cultures which could not be verified after long rehospitalization.

I would like to repeat once more what I said this morning, that the results from resection of so-called "nubbins," as I described small residues after long-term chemotherapy, are meaningless, and I should like to know how many of his patients had or would have had "nubbins" if chemotherapy had been used in continuous long-term treatment previous to resection. We cannot know what would have happened to such lesions had they not been disturbed.

But it is an interesting paper, or what we have heard of it was, and I certainly want to congratulate him on the results if they were obtained from active disease without long-term chemotherapy. I wish I were that good a surgeon.

DR. CHAMBERLAIN (Closing).—Dr. Himmelstein made a good point on fistulas. If we added our "late leaks" to the bronchial fistulas that we had, our figures would be essentially the same, approximately 10 per cent. In other words, we had 6 per cent bronchial fistulas and about the same number of "late leaks," 10 to 12 per cent in all.

Dr. Norman Wilson made some excellent points. We have come to the same conclusion, that whenever the indications for segmental resection are extended we were likely to get into trouble. As I pointed out, the majority of the patients who died had diffuse disease and poor functional reserve. We were trying desperately to salvage these patients by a minimal-sized operation for a maximum amount of disease. The operation cannot be extended too far. It is a segmental operation by name and the disease must be segmental in distribution.

Dr. O'Brien make two very excellent points. When we started this study we did not have chemotherapy, and at St. Albans Hospital we did twenty-six consecutive cases without chemotherapy. We found that those cases, in comparison with a similar number at Halloran Hospital, gave us essentially the same results. But that does not prove too much because they were carefully selected cases. This operation is not a dangerous one if the indications are proper. We are the first to admit that only the essential focus is removed and that we must attend carefully to the basic principles of postoperative management, such as obliteration of dead space by maintaining re-expansion. Because we know postoperative management, we are not hesitant to operate upon patients whose organisms have developed resistance to the antibiotics. We believe that antibiotics are no substitute for the basic principles of surgical management.

Dr. O'Brien's other point was an excellent one, too. I am inclined to agree with him in his differentiation of spreads and reactivations. He has made an astute observation. We all know we cannot see all the foci in the x-ray films that we discover at operation and probably some of the lesions we have called spreads may have been reactivations. If you wish, then the spreads may simply be added to the reactivations to get the total figure.

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ELECTROLYTE STUDIES IN PERICARDIAL RESECTION

WALTER B. CRANDELL, M.D., ANDREW YEOMANS, M.D. (BY INVITATION),
DAVID L. HOFFMAN, M.D. (BY INVITATION), AND
GEORGE H. STUECK, JR., M.D. (BY INVITATION)
WHITE RIVER JUNCTION, VT.

ALTHOUGH not the first to perform decortication of the heart, Schmieden¹ was early to acquire an experience with the procedure, and in 1926 recommended a regimen of dehydration by limitation of fluid intake and aspiration of pleural fluid in the preparation of such patients for surgery. Subsequently others have advised the preoperative removal of excessive fluid accumulations, some by more vigorous measures which have included the use of diuretics and a rigid restriction of sodium intake.²⁻⁷

It is not surprising that attempts to rid the body of a substance so important to homeostasis as sodium^{8, 9} might occasionally work to a disadvantage, and such a situation arising during the treatment of congestive heart failure has been described and recently named "the low salt syndrome."¹⁰ Peters¹¹ has pointed out that with a low concentration of sodium in the extracellular fluid, the cells of the tissues take up water and secondary disorders occur, chief of which is circulatory failure. He has also observed and emphasized that ill effects from sodium depletion can occur in the presence of edema, when the concentration of sodium in the serum and extracellular fluids is low, and even when the total quantity of sodium in the body may be excessive.

While performing certain metabolic and physiologic studies on two patients before, during, and after pericardial resection for constrictive pericarditis, we were amazed to find that one, a chronically ill, little 54-year-old man with advanced pulmonary silicotuberculosis, tolerated the operation well, while the other, aged 27 years, previously vigorous, but still muscular and strong in appearance, had a period of hypotension and oliguria for two days after operation and was generally slow to recover although his ultimate result was excellent. In reviewing our observations we have been chiefly impressed by the fact that though both men demonstrate evidence of a disturbed sodium metabolism, the aberrations were more severe in the younger man, and we believe they contributed considerably to the postoperative instability of his circulatory system.

METHODS

The patients were studied on the Metabolic Service during the "balance" period. Fluid intake and urinary output were carefully supervised. Standard techniques in metabolic studies were employed.¹² All food was prepared and served by the metabolic dietitian, refusals were weighed, their contents calculated

From the Surgical and Medical Services, Veterans Administration Hospital, White River Junction, Vt., and Dartmouth Medical School, Hanover, N. H.

Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 30, 1953.

and subtracted from the daily intake. The contents of the daily food intake for various constituents were calculated from acceptable tables.¹³⁻¹⁶ Check analyses were performed and these agreed with the calculated values within acceptable limits.¹² The patients were weighed daily in the fasting state. Individual urine specimens were voided into chemically clean Erlenmeyer flasks and pooled into twenty-four hour specimens which were kept under toluene and refrigeration until analysis could be accomplished. Urine, serum, and thoracentesis fluid sodium were determined by gravimetric procedure¹⁷ and flame photometry; urine, serum, and thoracentesis fluid potassium by a titrimetric procedure¹⁸ and flame photometry; urinary nitrogen by the macro-Kjeldahl method¹⁹; serum chloride by titrimetric means^{20,21} serum bicarbonate by the manometric Van Slyke method²²; hematocrit by the method of Wintrobe²³ corrected²⁴; specific gravity of blood and plasma by the copper sulfate method²⁵; blood, cell, and plasma volumes were determined with T-1824²⁶ and the hematocrit. Serum proteins and thoracentesis fluid protein were determined by sodium sulfate precipitation and micro-Kjeldahl nitrogen determination.²⁷

"Balance" as here used is the output of a constituent in relation to its intake for a twenty-four hour period. The intake is the sum of oral and parenteral intake (see later material for blood); the output is the sum of urinary output, loss through vomitus, estimated blood loss at operation and by removal of blood for analysis; fecal output, losses through sweating, insensible loss are not included. Neither patient had diarrhea; both operations were performed during cool weather. The volume of blood loss at operation was estimated; the blood loss by venipuncture for analysis was measured. The method of Moore and Ball²⁸ was used to calculate the amount of sodium, potassium, and nitrogen which transfusions and blood losses contributed to the "balances." The concentration of the various constituents lost by all blood losses was calculated on the basis of the following: a hematocrit of 44 per cent, a cell sodium content of 12.7, a cell potassium content of 103.6, and a cell chloride content of 48.2 meq. per liter; a serum sodium content of 140.8, a serum potassium content of 4.0, and a serum chloride content of 104.1 meq. per liter. These values are based on analyses performed in our laboratory on "normal" blood by one of us (A. Y.).²⁹ Thus, 1,000 ml. of blood lost would contain in the red blood cells of this liter: sodium 6 meq., potassium 46 meq. and chloride 21 meq.; in the serum, 83 meq. sodium, 2 meq. potassium and 59 meq. chloride.

The amounts of the various constituents given by transfusion of bank blood (blood + ACD solution) were calculated from analysis of two representative samples of bank blood. The average values of these analyses were: hematocrit 41 per cent, plasma sodium 47, cell sodium 6, plasma potassium 5, cell potassium 17, plasma chloride 21, and cell chloride 15 meq. per transfusion unit (average 565 ml.).

In computing fluid intake and output, blood loss was not included because the amounts withdrawn for various tests were relatively small, and the estimated operative blood loss was replaced by transfusion.

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Physical examination revealed a chronically ill, poorly developed, and poorly nourished little man who looked considerably older than his stated years. The neck veins were engorged. There was dullness at the right base below the angle of the scapula. The liver was 8 cm. below the costal margin. There was induration, enlargement, and tenderness of the lower pole of the left epididymis. Both lobes of the prostate were indurated and fixed. There was a nontender, firm, nodular, mobile mass in the region of the left seminal vesicle. The blood pressure was 108 to 120/90, paradoxical, weight 57 kilos ($125\frac{3}{4}$ pounds).

Laboratory Data.—Hemogram was within normal limits, sedimentation rate 19 mm. per hour (Westergren); venous pressure was elevated to 240 mm. of saline. Roentgen examination of the chest showed disseminated nodular densities throughout both lung fields with numerous small calcifications and pleural thickening at the right base. At the right apex there was an increase and some confluence of the nodularities suggesting an active tuberculous process. On fluoroscopy cardiac pulsations were diminished. Excretory urograms were normal except for elevation of the bladder floor consistent with prostatic enlargement. Sputum and urine cultures were positive for tubercle bacilli.

He was digitalized without loss of weight and after five days this medication was discontinued. On a low salt diet (2 Gm. sodium chloride) and mercurials he lost 5.5 kilos in one week. He required one mercurial injection a week to maintain this weight level. Streptomycin, 1 Gm., was begun Feb. 21, 1950, and given daily for 120 days. Pericardial resection by a left transpleural approach was performed on February 27, and a satisfactory decortication obtained. The patient tolerated the procedure well and immediate convalescence was uneventful although ultimate rehabilitation has been poor because of senescence, silicotuberculosis, and limited movement of the left shoulder associated with pain in the thoracotomy wound.

CLINICAL OBSERVATIONS

The immediate response of the two men to operation was in direct contrast to their general appearance. D. T., the young game warden, came to the operating room with his normal blood pressure of 120 to 125/80 to 90 mm. mercury depressed by preoperative medication to 100/65. It returned to the normal level following induction, but after one hour and a half began to rise in stages, reaching 150/90 about an hour later; it remained at that level for forty-five minutes then began a gradual decline over the next six hours, falling below 100/60 as he left the operating room to an unstable range of 50 to 60/30 to ?? (Fig. 1). In spite of four blood transfusions hypotension developed and persisted for forty-eight hours. The night following operation was particularly critical. The margin between shock and pulmonary edema was so narrow that despite every effort and attention of the staff he developed both. There was oliguria to the extent that only 55 c.c. were produced the day of operation, 335 c.c. the day following, and 975 c.c. the next day in spite of corresponding fluid intake of 3,850 c.c., 7,700 c.c. and 5,430 c.c. (Table II).

The possibility that a deficiency of sodium was a factor in this complex clinical picture was considered at the time, and during the first night 1,720 c.c.

potassium was calculated from average values of the Donnan ratios, serum concentrations, and assumed "normal" water concentration of the serum.³⁰

Venous pressures were determined according to the procedure of Lyons and his associates.³¹ Arm-to-tongue circulation time was done in duplicate using 3 c.c. of 20 per cent sodium dehydrocholate intravenously.

CASE REPORTS

CASE 1.—D. T., a 27-year-old game warden, was admitted Sept. 19, 1949, for the surgical relief of constrictive pericarditis. Previously healthy, one year and a half before he had developed an acute pericarditis with effusion for which he was first admitted. Followed closely since, he improved slowly over a period of several months, and was able to return to work with some restriction of activity. Six months prior to operation, dyspnea and edema recurred and progressed, eventually requiring hospitalization. There was a right pleural effusion, elevated venous pressure (295 cm. water), an enlarged liver, ascites, and heart of normal size with diminished movement. Fibrous constriction appeared to be developing. Decortication was recommended but deferred by the patient. Bed rest, diuretics, a limited salt intake (2 Gm. sodium chloride or 34 meq. sodium per day), and a right thoracentesis (1 L.) effected a weight loss of 9.5 kilos (21 pounds.) in six days to 80.8 kilos. The patient went home on the same low sodium diet to which, with two admitted infractions, he adhered for the 10-week period prior to operation.

Physical examination revealed a husky, muscular young man who did not appear acutely ill. There was evidence of fluid in the right pleural cavity below posterior D6. The liver was 8 cm. below the costal margin, and there were signs of some free abdominal fluid. There was no peripheral edema. The blood pressure was 120/70, weight 86 kilos (189½ pounds).

Decortication of the heart was performed Sept. 28, 1949, through a left transpleural approach. Pleural adhesions were dense and vascular. All intrapleural and intrapericardial structures were red and swollen, causing a widespread ooze difficult to control, resulting in more than the ordinary loss of blood. Although in the immediate postoperative period he developed hypotension and oliguria, later convalescence was satisfactory, and now, four years later, he works strenuously as a game warden and denies any physical limitation whatsoever.

CASE 2.—J. L., a 54-year-old man, was admitted Dec. 8, 1949, because of anorexia, weight loss, and fever. He had worked as a sandblaster and stone cutter for thirty-five years, most of the time without adequate protection. After a chest film four years before he was told he had "spots on his lungs." Four months prior to admission he was acutely ill with substernal pain and fever of 105° F. A diagnosis of acute pericarditis was made at another hospital. Two months before admission he became jaundiced and developed upper abdominal discomfort, chiefly after eating; this resulted in a loss of appetite. After two weeks the jaundice cleared but the other symptoms persisted and an evening fever was detected.

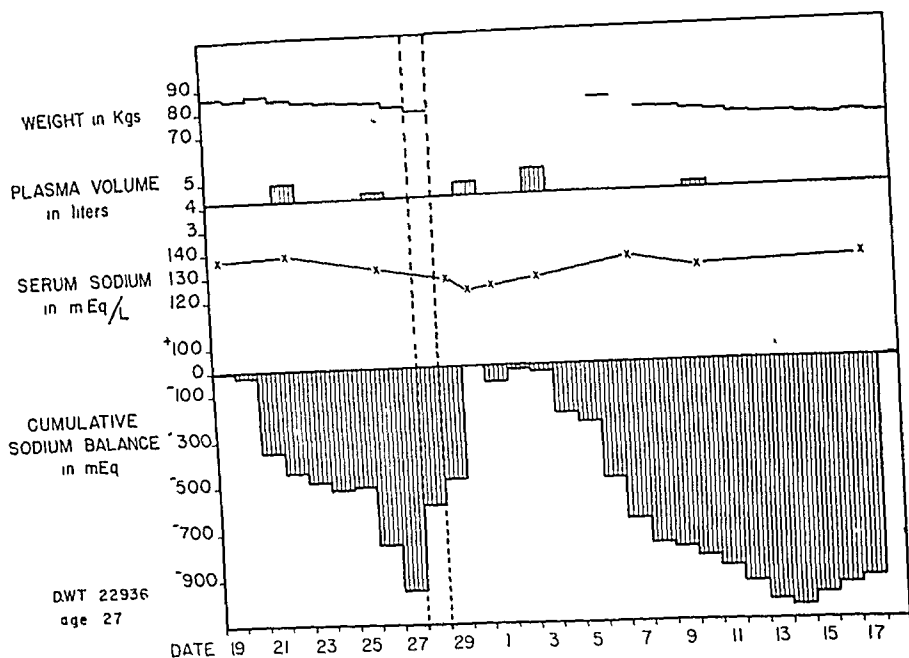


Fig. 2.—Cumulative sodium balance, serum sodium, plasma volume, and weight of the patient in Case 1. The operative day is denoted by the vertical broken lines. For explanation of cumulative "balance," see text.

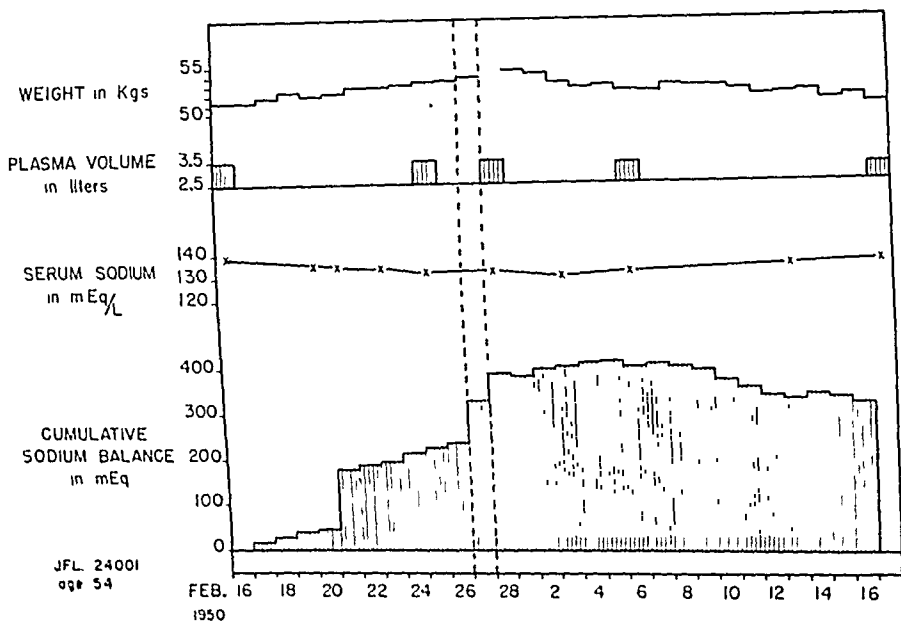


Fig. 3.—Cumulative sodium balance, serum sodium, plasma volume, and weight of the patient in Case 2. The operative day is denoted by the vertical broken lines. For explanation of the cumulative "balance," see text.

of physiologic saline was given between midnight and morning (Fig. 1). Although the blood pressure level improved, the development of pulmonary edema necessitated discontinuance of the venoclysis for about four hours. On the first postoperative day, he was given 1,900 c.c. of physiologic saline and took some fluids by mouth, receiving 310 meq. of sodium that day, still without stabilizing his blood pressure. On the second postoperative day he was given 2,000 c.c. of saline containing 310 meq. of sodium. Late in the afternoon, the serum sodium level on blood drawn that morning was reported to be 123.2 meq. per liter.

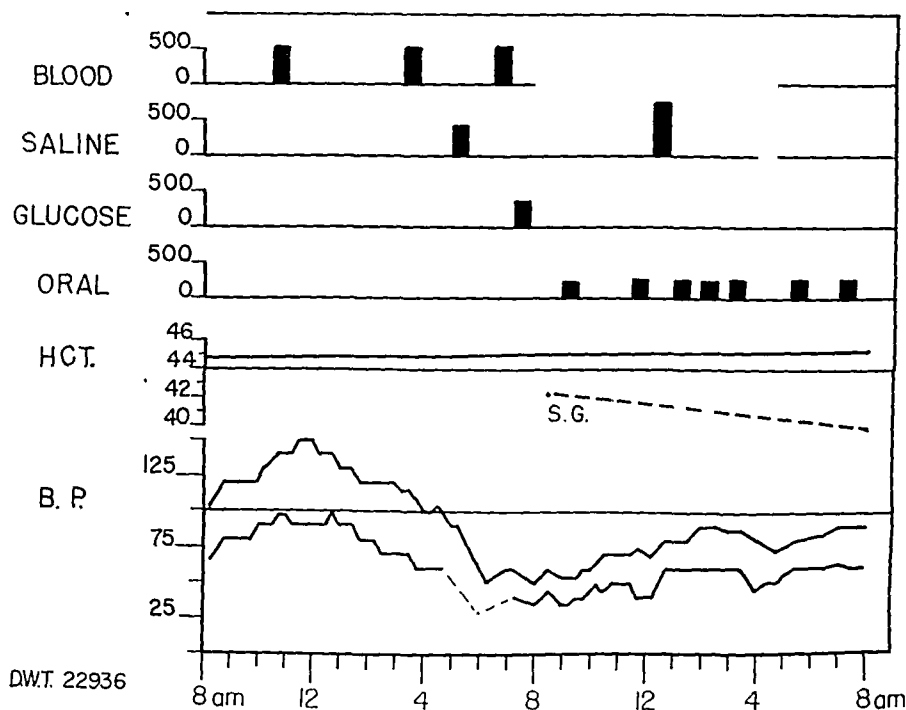


Fig. 1.—The blood pressure, hematocrit, and fluid intake of the patient in Case 1 for the operative day starting at 8:00 A.M. HCT = hematocrit; S. G. = hematocrit determined from the specific gravity of blood and plasma. (See reference 25.)

It was then decided to give hypertonic saline, and 200 c.c. of a 4 per cent solution of sodium chloride containing 123 meq. of sodium was injected by intravenous drip. From the clinical standpoint this was the turning point in the course. The patient soon looked and felt much better, the blood pressure became more stable, and he was not hypotensive again. Urine volume increased during the night and was copious the next day (Fig. 4, and Table II).

J. L., the frail elderly man with silicotuberculosis, came to the operating room with his normal blood pressure of 100 to 110/70 to 80 essentially unchanged. Following induction it stabilized at 120/90, where it remained for two hours before declining to 100/80; he responded to transfusion after an hour and left the operating room at a level of 110/70. During the next twenty-

conservation and lost 750 meq. of sodium (44 Gm. of salt) in three chest taps. There was an associated loss of 8 kilos (17½ pounds) body weight (Tables II and III). Repeated thoracenteses following operation produced a further loss of 590 meq. of sodium and on one occasion, the first postoperative day, accounted for a loss of nearly 200 meq. of sodium when an attempt was being made to treat sodium deficiency by giving 300 meq. intravenously, resulting in a net gain to the body that day of only 100 meq. of sodium.

A comparison of the daily urinary sodium excretion patterns in these two patients reveals the following: 1. the patient in Case 1 was initially excreting more sodium than he took in and this occurred at a relatively "normal" level

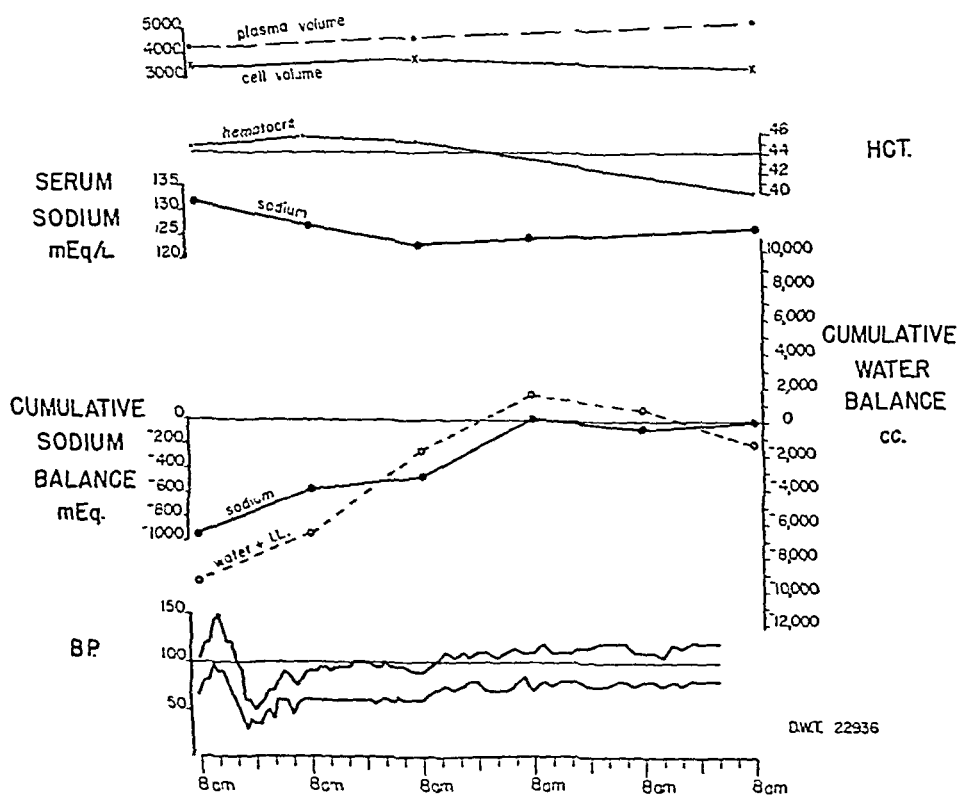


Fig. 5.—Blood pressure, cumulative sodium balance, cumulative water balance, serum sodium concentration, hematocrit, cell volume, and plasma volume of the patient in Case 1; the observations start on the day of operation and include the first four postoperative days. Cumulative water balance is computed from measurement of the fluid intake and output with an additional allowance of 700 c.c. (afebrile) daily insensible loss before operation and 1,000 c.c. (febrile) after operation.

of intake. The patient in Case 2 excreted insignificant amounts of sodium on a "low" intake, and this remained constant throughout the preoperative period, with the exception of the clearance day. 2. The patient in Case 1 decreased daily sodium urinary output when intake was markedly reduced, but these levels were never so low as those in Case 2 on approximately the same level of

four hours his condition was good and continued to improve. The blood pressure ranged over 105 to 120/80 to 60, never dropping below 100 systolic. Urine output was 630 c.c. the day of operation (all postoperative) and 1,000 c.c. and 1,175 c.c. the two following days (Table III).

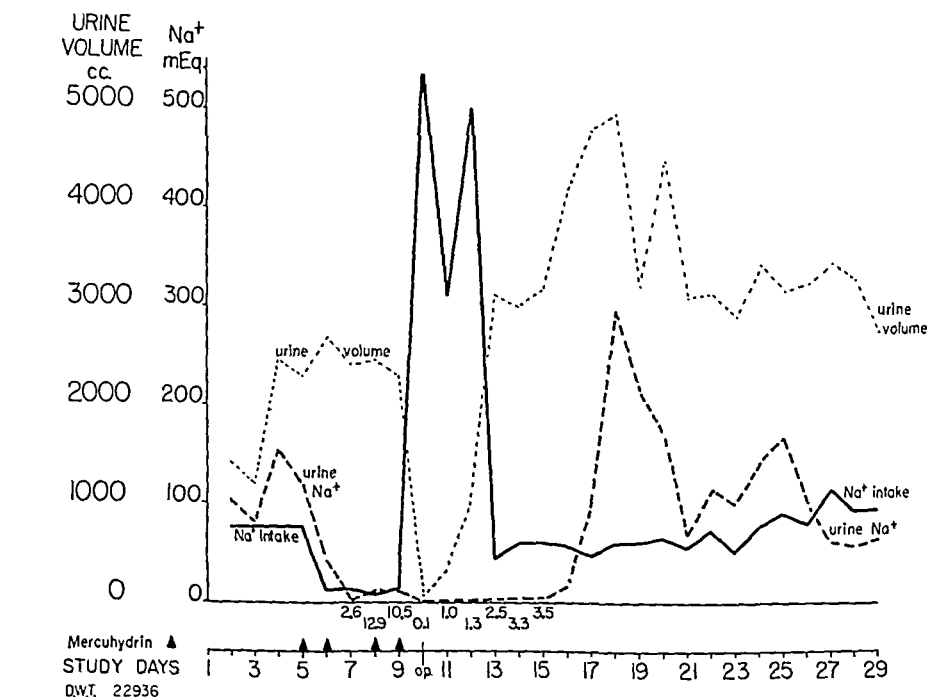


Fig. 4.—Urine volume, daily urinary sodium excretion, and daily sodium intake of the patient in Case 1. The operative day and the days of Mercuhydrin Sodium Solution administration are noted at the bottom of the figure.

LABORATORY OBSERVATIONS

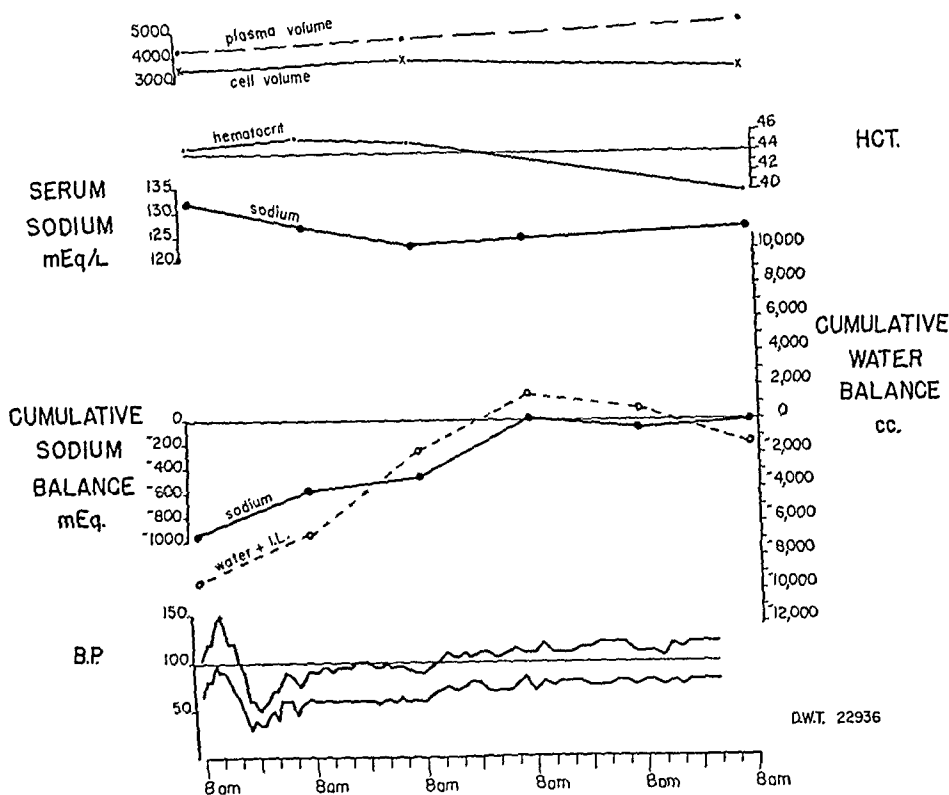
Data obtained are arranged in tabular form and presented in Tables I to VII. See pages 495 to 500.

The most striking difference between the two cases, in which Case 1 compared unfavorably, was in the metabolism of sodium. This is brought out most forcefully by adding and subtracting the day to day sodium balances of each of the men and presenting the excess or deficit from the beginning of the balance study to any one day in the study period as a simple figure of sodium credit or debit (Figs. 2 and 3 and Table I).

It can be seen that whereas the patient Case 2 had within his body on the morning of operation some 240 meq. of sodium more than at the beginning of the study, the patient in Case 1 came to the operation with 950 meq. of sodium less. Both men were on low sodium diets and had been for two months prior to the study. Whereas the patient in Case 2 excreted little sodium in urine, suffered no major losses, and was able to gain 150 meq. during a test of renal function with sodium hippurate, the patient in Case 1 did not effect at first any renal

conservation and lost 750 meq. of sodium (44 Gm. of salt) in three chest taps. There was an associated loss of 8 kilos (17½ pounds) body weight (Tables II and III). Repeated thoracenteses following operation produced a further loss of 590 meq. of sodium and on one occasion, the first postoperative day, accounted for a loss of nearly 200 meq. of sodium when an attempt was being made to treat sodium deficiency by giving 300 meq. intravenously, resulting in a net gain to the body that day of only 100 meq. of sodium.

A comparison of the daily urinary sodium excretion patterns in these two patients reveals the following: 1. the patient in Case 1 was initially excreting more sodium than he took in and this occurred at a relatively "normal" level



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ure, cumulative sodium balance, cumulative water balance, serum
 atocrit, cell volume
 the day of operati
 is computed from
 of 700 c.c. (afebr
 1,000 c.c. (febrile) after operation.

of intake. The patient in Case 2 excreted insignificant amounts of sodium on a "low" intake, and this remained constant throughout the preoperative period, with the exception of the clearance day. 2. The patient in Case 1 decreased daily sodium urinary output when intake was markedly reduced, but these levels were never so low as those in Case 2 on approximately the same level of

intake. The response was undoubtedly influenced by the administration of diuretics. 3. The operative day in both patients is characterized by very low levels of sodium output in relation to intake. However, the patient in Case 1 manifested an anuria, 55 c.c. output, while the patient in Case 2 showed only a reduction of urine volume from the preoperative level. 4. During the first five and four days after operation, both patients showed reduced daily urinary sodium excretion.

Data relative to the potassium "balances" in these patients will be found in Tables IV and V. There was a slightly negative potassium balance immediately before operation in Case 1 in contrast to Case 2 which was in a slightly positive potassium balance. On the operative day, the patient in Case 1 showed a slightly positive balance, because of anuria and transfusions, while the patient in Case 2 showed a negative balance. After operation, the immediate potassium balance was positive in Case 1 and negative in Case 2. The patient in Case 1 then remained in a slightly negative potassium balance in contrast to the patient in Case 2 who returned to a slightly positive balance. The potassium balance in Case 2 is more typical of that encountered in patients undergoing a similar degree of surgical trauma than is the balance in Case 1.²⁸ The pattern of the potassium balance in the patient in Case 1 with a normal serum potassium in the immediate postoperative course would appear to rule out potassium depletion as an important etiological factor contributing to the abnormalities of the postoperative course. The serum potassium of the patient in Case 2 reached its lowest levels at a time when the positive potassium balance was being established.

Data relative to the nitrogen balance in both patients are given in Tables IV and V. There was a negative nitrogen balance in Case 1 immediately before operation which was in part due to a therapeutic change in diet and nitrogen loss as protein in the thoracenteses. On the operative day the patient was in nitrogen equilibrium with a very low urine output. There then followed seven days of negative balance with impaired kidney function, elevated blood NPN, diminished urine output on an adequate fluid intake, and nitrogen loss in thoracenteses. This in turn was succeeded by eleven days of approximate nitrogen equilibrium, the balance becoming definitely positive on the last study day. This illustrates the role of the removal of protein nitrogen by thoracenteses in contributing to negative nitrogen "balance." In contrast, the balance in the patient in Case 2 was positive before operation, was definitely negative on the operative day, and remained negative for four days, becoming positive on the fifth day and remaining so throughout the remainder of the study. The pattern of his nitrogen balance was considered typical of a patient undergoing a surgical procedure of this degree.²⁸

Serum and blood constituents, blood and plasma volumes, circulation time and venous pressure during and after the metabolic study period are presented in Tables VI and VII. Both men had abnormally low serum sodium levels at

some time (normal 135 to 145 meq. per liter). However, the patient in Case 1 was definitely subnormal two days prior to operation, reached a quite low level (123.2 meq. per liter) two days after operation, and was persistently below normal over a span of four weeks.

In Case 1, the nonprotein nitrogen values were moderately elevated during the immediate postoperative period, associated with a low urine output.

Blood and plasma volumes obtained during the study period were normal or above³² at all times in both patients. One such determination obtained in Case 1 two days after operation, when he was still hypotensive, was above normal values for a man of his weight range. Moreover, on other occasions when he was clinically much improved he had lower values of both blood and plasma volumes.

The venous pressure of the patient in Case 1 was high before operation and showed a good response to the procedure. On the other hand, the patient in Case 2, whose venous pressure was not so high prior to operation, had no drop at first, and though ultimately declining it did not reach a similar low level.

TABLES I TO VII

TABLE I. CASES 1 AND 2. COMPARISON OF CUMULATIVE SODIUM "BALANCES"

DATE 1949	CASE 1 CUMULATIVE "BALANCE" MEQ.	CASE 2 CUMULATIVE "BALANCE" MEQ.	DATE 1950
9/18		+18.1	2/17
9/19		+29.6	2/18
9/20	-27.1	+41.2	2/19
9/21	-354.9	+47.8	2/20
9/22	-443.2	+180.6	2/21
9/23	-486.7	-191.9	2/22
9/24	-517.1	-196.5	2/23
9/25	-507.4	-216.4	2/24
9/26	-757.2	-225.6	2/25
9/27	-951.9	+237.0	2/26
Operation 9/28	-586.1	-329.0	2/27
9/29	-483.9	+390.3	2/28
9/30	+1.0	-385.3	3/1
10/1	-70.8	-399.8	3/2
10/2	-14.8	-405.1	3/3
10/3	-27.3	-413.9	3/4
10/4	-208.1	+415.7	3/5
10/5	-256.6	+404.0	3/6
10/6	-491.7	+410.0	3/7
10/7	-662.1	+402.5	3/8
10/8	-770.5	+395.1	3/9
10/9	-784.1	+373.5	3/10
10/10	-824.7	+350.2	3/11
10/11	-872.8	-339.5	3/12
10/12	-937.6	-323.8	3/13
10/13	-1015.6	+335.3	3/14
10/14	-1038.6	-329.9	3/15
10/15	-988.2	+320.6	3/16
10/16	-953.1		
10/17	-922.9		

For explanation of cumulative "balance," see text.

TABLE II. CASE I

DATE	WGT. KILOGS.	FLUID "BALANCE"					SODIUM "BALANCE"					"BALANCE"
		FLUID INTAKE C.C.	URINE VOLUME C.C.	LOSS CHEST TAPS C.C.	TOTAL FLUID LOSS C.C.	"BALANCE"	TOTAL INTAKE MEQ.	LOSS CHEST TAPS MEQ.	LOSS BLOOD MEQ.	LOSS URINE MEQ.	TOTAL OUTPUT MEQ.	
9/20	85.9	2430	1415		1415	+1015	77			104.1	104.1	-27.1
9/21	86.2	1230	1195	2347	3542	-2310	77	322.2		82.6	404.8	-327.8
9/22	84.3	2940	2450		2450	+490	77		10	155.3	165.3	-88.3
9/23	83.6	2810	2285		2285	+525	77			120.5*	120.5	-43.5
9/24	83.1	2720	2670		2670	+50	12.3			42.7*	42.7	-30.4
9/25	82.8	2140	2400		2400	-260	12.3			2.6	2.6	+9.7
9/26	82.2	2620	2445	1800	4245	-1625	8.9	235.8	10	12.9*	258.7	-249.8
9/27	79.8	1950	2285	1500	3785	-1835	12.3	196.5	168	105.5*	207.0	-194.7
9/28	77.9	3850	55		55	+3795	533.9			0.1	168.1	+305.8
9/29		7700	335	1500	1835	+5865	309.7	196.5	10	1.0	207.5	+102.2
9/30		5430	975		975	+4455	496.2		10	1.3	11.3	+484.9
10/1		3500	3105	900	4005	-505	45.5	109.8	5	2.5	117.3	-71.8
10/2		3450	2990		2990	+460	60.8	59.8	10	3.3	3.3	+56.0
10/3		3955	3170	475	3645	+310	57.0	221.2		3.5	73.3	-12.5
10/4		5160	4150	1700	5850	-690	47.7			16.6	237.8	-180.8
10/5		3470	4750		4750	-1280	60.1			96.2	96.2	-48.5
10/6	81.6	4130	4925		4925	-795				295.2	295.2	-235.1
10/7		3190	3455	50	3505	-315	65.5	6.7	10	214.9	231.6	-170.4
10/8	76.5	4335	4460		4460	-125	55.5			173.9	173.9	-108.4
10/9	76.2	3620	3070		3070	+550	73.3			69.1	69.1	-13.6
10/10	75.3	4680	3120		3120	+1500	51.0			113.9	113.9	-40.6
10/11	74.5	2990	2890		2890	+100	76.4			99.1	99.1	-18.1
10/12	73.6	4010	3410		3410	+600	88.7			141.2	141.2	-64.8
10/13	72.7	3360	3140		3140	+220	79.0			166.7	166.7	-78.0
10/14	72.6	4070	3230		3230	+840	114.0			102.0	102.0	-23.0
10/15	71.8	4040	3435		3435	+605	93.0			63.6	63.6	+50.4
10/16	71.6	3860	3270		3270	+590	94.3			57.9	57.9	+35.1
10/17	71.8	3710	2740		2740	+970				64.1	64.1	+30.2

The day of operation is 9/28.

For definition of "balance" and the method of handling losses and gains of the various constituents in blood given and removed in calculation of the "balances" in this and subsequent Tables, see METHODS.
 *Mercurhydrin, 2 c.c., administered intravenously.

TABLE III. CASE 2

TABLE III. CASE 2												
SODIUM "BALANCE"												
FLUID "BALANCE"												
DATE	WGT. KILOS.	FLUID "BALANCE"					SODIUM "BALANCE"					
		FLUID INTAKE C.C.	URINE VOLUME C.C.	LOSS CHEST TAPS C.C.	TOTAL FLUID LOSS C.C.	"BALANCE" C.C.	TOTAL INTAKE MEQ.	LOSS CHEST TAPS MEQ.	LOSS BLOOD MEQ.	LOSS URINE MEQ.	TOTAL OUTPUT MEQ.	"BALANCE" MEQ.
1950												
2/17	51.4	1770	1210		1210	+560	24.1		5.5	0.46	6.0	+18.1
2/18	51.9	1390	1260		1260	+130	11.9			.35	0.4	+11.5
2/19	52.4	1870	1100		1100	+770	11.9			.32	0.3	+11.6
2/20	51.8	2010	1210		1210	+800	11.9		4.9	.39	5.3	+6.6
2/21	52.1	2150	1330		1330	+820	171.1†		10.0	28.3	38.3	+132.8
2/22	52.9	1770	1170		1170	+600	11.9			.62	0.6	+11.3
2/23	52.9	1530	995		995	+535	11.9		6.9	.41	7.3	+4.6
2/24	53.1	1830	855		855	+975	26.5†		6.2	.43	6.6	+19.9
2/25	53.4	1530	965		965	+565	11.9		2.4	.32	2.7	+9.2
2/26	53.5	1530	1175		1175	+355	11.9			.50	0.5	+11.4
2/27	53.8	3980	610		610	+3370	177.8		83.0	2.78	85.8	+92.0
2/28		3620	1020		1380*	+2240	76.4		6.2	3.61	15.1†	+61.3
3/1	54.6	2235	1295	250	1545	+690	29.0†	25.2	7.5	1.25		+14.5
3/2	54.2	1860	1100		1100	+760	15.0		4.9	0.69	5.6	+5.3
3/3	53.4	1620	785		785	+835	10.9			4.15	4.2	+8.8
3/4	52.7	2080	1110		1110	+970	13.0			7.6	7.6	+1.8
3/5	52.9	1500	625		625	+875	9.4		7.5	17.8	25.3	-11.7
3/6	52.4	1500	755		755	+745	13.6		4.2	18.5	22.7	+6.0
3/7	52.3	1920	740		740	+1180	28.7†			17.9	17.9	-7.5
3/8	52.8	1530	875		875	+655	10.4			18.1	18.1	-7.4
3/9	52.7	1630	1240		1240	+390	10.7			31.5	31.5	-21.6
3/10	52.7	1870	1240		1240	+630	9.9			33.6	33.6	-23.3
3/11	52.2	1435	1365		1365	+70	10.3			22.6	22.6	-10.7
3/12	51.6	1630	975		975	+655	11.9		4.9	22.7	27.6	-15.7
3/13	52.0	1390	1070		1070	+320	29.6†		4.5	14.6	19.1	+11.5
3/14	52.1	2165	1490		1490	+675	11.9			17.3	17.3	-5.4
3/15	51.3	1630	1135		1135	+495	11.9			21.2	21.2	-9.3
3/16	51.6	1630	1225		1225	+405	11.9		7.5	8.6		
3/17	50.9	1390	950		950	+440						

See legend Table II for explanation.

The operative day is 2/27.

*Includes vomitus, 360 c.c.

†Includes parenteral sodium given for renal clearance studies.

‡Includes 5.3 meq. sodium lost in vomitus.

TABLE IV. CASE 1

DATE	POTASSIUM "BALANCE"					NITROGEN "BALANCE"						
	TOTAL INTAKE MEQ.	LOSS CHEST TAP MEQ.	LOSS BLOOD MEQ.	LOSS URINE MEQ.	TOTAL OUTPUT MEQ.	"BALANCE" MEQ.	TOTAL INTAKE GM.	LOSS CHEST TAP GM.	LOSS BLOOD GM.	LOSS URINE GM.	TOTAL OUTPUT GM.	"BALANCE" GM.
1949												
9/19			.3						0.7			
9/20	110.1			85.3	85.3	+24.8	25.6			15.1	15.1	+10.5
9/21	109.2	6.0		28.2	34.2	+75.0	25.6	13.7		15.8	29.5	-3.9
9/22	112.2		.3	99.1	99.4	+12.8	25.6		0.7	15.8	16.5	+9.1
9/23	110.1			98.4	98.4	+11.7	25.6			16.2	16.2	+9.4
9/24	59.9			100.2	100.2	-40.3	13.2			15.4	15.4	-2.2
9/25	62.8		.3	58.0	58.0	+4.8	13.2		0.7	15.4	15.4	-2.2
9/26	60.7	5.4		76.0	81.7	-21.0	8.3	14.2		13.2	28.1	-19.8
9/27	59.9	4.5		58.9	63.4	-3.5	13.2	11.8		11.3	23.1	-9.9
9/28	20.0		4.0	5.4	9.4	+10.6	11.2		11.2	0.5	11.7	-0.5
9/29	53.1	5.0	.3	20.5	25.8	+27.3	4.7	9.9	0.7	1.9	12.5	-7.8
9/30	14.9		.3	44.4	44.7	-29.8	3.0		0.7	7.6	8.3	-5.3
10/1	37.9	3.3	.1	64.5	67.9	-30.0	8.3	3.8	0.4	21.0	25.2	-16.9
10/2	71.1			62.4	62.4	+8.7	12.1			24.3	24.3	-12.2
10/3	64.7	1.9	.3	56.9	59.1	+5.6	14.1	1.8	0.7	18.5	21.0	-6.9
10/4	57.6	6.6		78.4	85.0	-27.4	13.2	9.5		18.9	28.4	-15.2
10/5	66.0			87.0	87.0	-21.0	14.5			18.1	18.1	-3.6
10/6	77.4			92.7	92.7	-15.3	17.7			18.2	18.2	-0.5
10/7	76.6	0.2	.3	86.9	87.4	-10.8	17.2	0.2	0.7	13.9	14.8	+2.4
10/8	93.2			124.5	124.5	-31.3	21.7			20.2	20.2	+1.5
10/9	57.2			88.3	88.3	-31.1	11.0			15.8	15.8	-4.8
10/10	98.2			117.9	117.9	-19.7	19.7			20.6	20.6	-0.9
10/11	78.0			81.8	81.8	-3.8	17.4			17.8	17.8	-0.4
10/12	84.8			91.6	91.6	-6.8	19.9			19.4	19.4	+0.5
10/13	88.3			93.4	93.4	-5.1	17.8			18.9	18.9	-1.1
10/14	85.5			94.8	94.8	-9.3	19.8			19.3	19.3	+0.5
10/15				71.6	71.6		18.5			18.0	18.0	+0.5
10/16				84.6	84.6		20.1			19.8	19.8	+0.3
10/17				71.2	71.2		23.8			16.0	16.0	+7.8

For explanation see page 17

For explanation see Table II.
The operation day is 9/23.

TABLE V. CASE 2

DATE	POTASSIUM "BALANCE"						NITROGEN "BALANCE"					
	TOTAL INTAKE (MEQ.)	LOSS CHIST TAPS (MEQ.)	LOSS BLOOD (MEQ.)	LOSS URINE (MEQ.)	TOTAL OUTPUT (MEQ.)	"BALANCE" (MEQ.)	TOTAL INTAKE (GM.)	LOSS CHIST TAPS (GM.)	LOSS BLOOD (GM.)	LOSS URINE (GM.)	TOTAL OUTPUT (GM.)	"BALANCE" (GM.)
2/17	80.0			60.4	60.4	+19.6	15.4			12.0	12.0	+3.4
2/18	84.0			72.0	72.0	+12.0	15.3			13.8	13.8	+1.5
2/19	84.0			55.0	55.0	+29.0	15.4			10.8	10.8	+4.6
2/20	79.5			69.1	69.1	+10.4	15.1			11.9	11.9	+3.2
2/21	85.5			102.6	102.6	-17.1	15.3			14.2	14.2	+0.6
2/22	82.2		0.2	60.0	60.2	+22.2	15.4		0.5	13.1	13.1	+2.3
2/23	78.0		0.2	55.0	55.2	+22.8	15.1		0.5	12.8	12.8	+1.8
2/24	85.6			56.6	56.6	+29.0	15.3			11.0	11.0	+4.3
2/25	82.2			57.3	57.3	+24.9	15.4			11.8	11.8	+3.6
2/26	77.5			63.1	63.1	+14.4	12.8			11.9	11.9	+0.9
2/27	15.0		2.0	71.4	73.4	-58.4	8.1		5.0	7.7	12.7	-4.6
2/28	42.6	2.4*		62.1	64.5	-21.9	4.7			9.6	9.6	-4.9
3/1	32.6	0.7	0.2	42.7	43.6	-11.0	3.4	1.9	0.5	11.5	13.9	-10.5
3/2	35.0			23.7	23.7	+11.3	4.9			8.3	8.3	-3.4
3/3	35.1			24.6	24.6	+10.5	5.7			6.9	6.9	-1.2
3/4	47.6			36.4	36.4	+11.2	8.5			8.1	8.1	+0.4
3/5	58.8			36.0	36.0	+22.8	5.3			7.5	7.5	+0.8
3/6	53.0		0.2	39.3	39.5	+13.5	10.8		0.5	8.7	9.2	+1.6
3/7	43.8			35.6	35.6	+8.2	9.5			8.1	8.1	+1.4
3/8	47.5			40.5	40.5	+7.0	9.7			9.5	9.5	+0.2
3/9	59.6			46.5	46.5	+13.1	11.3			9.6	9.6	+1.7
3/10	72.6			52.0	52.0	+20.6	12.8			10.6	10.6	+2.0
3/11	71.5			66.3	66.3	+5.2	12.6			10.6	10.6	+4.7
3/12	82.0			65.6	65.6	+16.4	15.3			12.3	12.3	+2.8
3/13	79.6			84.1	84.1	-4.5	15.1			11.7	11.7	+3.7
3/14	54.2			69.0	69.0	+15.2	15.4			12.1	12.1	+2.9
3/15	78.2			64.4	64.4	+13.8	15.0			13.5	13.5	+1.6
3/16	79.2			82.4	82.4	-3.2	15.1			11.0	11.0	+4.4
3/17	84.2			55.6	55.6	+28.6	15.4					

For explanation see Table II.

The day of operation is 2/27.

*Vomitus, 360 c.c.

TABLE VI. CASE 1. SERUM AND BLOOD CONSTITUENTS, BLOOD AND PLASMA VOLUMES, CIRCULATION TIME, AND VENOUS PRESSURE

DATE	SERUM					BLOOD							VENOUS PRESSURE (MM. SALINE)
	SODIUM (MEQ./L.)	POTASSIUM (MEQ./L.)	CHLORIDE (MEQ./L.)	ALBUMIN (GM. %)	GLOBULIN (GM. %)	TOTAL PROTEINS (GM. %)	NPN (MG. %)	HEMA-TOCRIT (%)	BLOOD VOLUME (C.C.)	PLASMA VOLUME (C.C.)	RED CELL VOLUME (C.C.)	CIRC. TIME (SEC.)	
9/19 1949	136.9	4.2	106.0	4.4	2.8	7.2	35	42.9	8741	5000	3741	34	320
9/22	138.6	3.4	104.0	3.8	2.2	6.0	29	42.8				37	350
9/26	132.0	4.0	99.5	3.6	3.2	6.8	50	44.6	7865	4357	3508	32	295
9/29	127.1	4.4	96.6	3.5	2.5	6.0	56	45.7					
9/30	123.2	4.9	94.8	3.8	2.6	6.4	56	45.1	8599	4721	3878		
10/1	124.3	4.8	96.0	4.2	2.0	6.2	66						
10/3	126.6	5.2	98.0	3.1	2.6	5.7	39	39.7	8662	5223	3439		165
10/7	134.7	5.4	99.9	3.4	2.8	6.2	30					18	
10/10	129.8	3.4	100.0	3.3	4.1	7.4	34	38.3	7164	4420	2744		
10/12		3.4		3.6	4.0	7.6							
10/17	131.5	3.8		3.5	4.6	8.1	29	39.8				20	92
10/24	134.4		98.5	3.5	3.8	7.3	28	39.0					
11/30	135.7	3.9	101.9	3.9	4.0	7.9	29						
3/8/50	138.3	5.1	99.0	4.5	2.5	7.0	37	47.5	8080	4247	3833		

The operative day is 9/28.

TABLE VII. CASE 2. SERUM AND BLOOD CONSTITUENTS, BLOOD AND PLASMA VOLUMES, CIRCULATION TIME, AND VENOUS PRESSURE

DATE	SERUM					BLOOD							VENOUS PRESSURE (MM. SALINE)	
	SODIUM (MEQ./L.)	POTAS- SIUM (MEQ./L.)	CHLORIDE (MEQ./L.)	BICAR- BONATE (MEQ./L.)	ALBUMIN (GM. %)	GLOBULIN (GM. %)	TOTAL PROTEINS (GM. %)	NPN (MG. %)	HEMA- TOCRIT (%)	BLOOD VOLUME (C.C.)	PLASMA VOLUME (C.C.)	RED CELL VOLUME (C.C.)		CIRC. TIME (SEC.)
1950 2/16	139.4	3.9	104	24.2	3.7	4.6	8.3	33	43.1	6134	3490	2644	32	200
2/17														
2/20	136.3	4.2	105	23.1	3.6	4.6	8.2	34	43.0				23	167
2/21	135.5								43.8					
2/23	134.4	4.0	103	24.1	3.3	4.3	7.6	36	41.4					
2/24									41.4					
2/25	132.5								39.9	5824	3506	2328		165
2/28	133.1	3.6	101	17.8	3.5	3.7	7.2	41	40.4	5815	3466	2349	22	180
3/1									42.2					
3/3	130.8	3.3	97	19.3	3.4	4.0	7.4	33	43.7					
3/4														
3/6	132.4	3.0	98	20.4	3.7	4.0	7.7	34	43.7	6406	3404	3002	20	175
3/13	134.9	4.0	101	22.3	3.4	4.5	7.9	29	41.5				26	182
3/14													18	130
3/17	136.0				2.8	5.2	8.0	33	41.9	5718	3322	2396		

The operative day is 2/27.

DISCUSSION

Sodium depletion is usually accompanied by dehydration, and circulatory failure is recognized as an important clinical feature of this condition.^{9, 33-36} In experimental salt depletion in animals it has been demonstrated that the circulatory impairment is due chiefly to a lowered plasma volume secondary to shrinkage of extracellular fluid but is also unfavorably influenced by the presence of hyponatremia.³⁷⁻⁴² With the increasing use of intravenous saline-free fluids⁴²⁻⁴⁴ and the application of regimens of sodium restriction to the treatment of edematous states, particularly those of a cardiovascular nature,^{10, 45, 46} instances are encountered in which a sodium deficiency exists in the absence of dehydration and when there may be an increase of the total amount of sodium in the body.^{10, 11, 47-49} Hyponatremia is seen in the presence of edema. In this situation the pathogenesis of the circulatory impairment is not clearly understood, but Peters¹¹ suggests that there may be altered cellular function associated with maldistribution of water within the body.

Features favoring sodium depletion in Case 1 are as follows:

For two months prior to the preoperative study period he had been on a low sodium intake of about 34 meq. per day. In spite of the use of diuretics and a good urine volume there was a low urinary sodium output in the three or four days preceding operation.⁵⁰ There was a cumulative deficit of 950 meq. of sodium in the preoperative phase of the study period. Since the average total exchangeable sodium in a 70 kilo man is 2,950 meq.,⁵¹ it can be appreciated that the magnitude of such a deficit occurring in eight days is considerable. In the latter part of the second postoperative day there was clinical improvement which coincided with the correction of the deficiency by hypertonic saline.

Abnormally low serum sodium levels are considered good evidence for sodium depletion, since with experimental depletion, the level of serum sodium is conserved for a time by loss of water, and then falls when the sodium deficit becomes considerable. Apparently osmotic pressure of the body fluids is first conserved at the expense of volume before yielding to hypotonicity.^{9, 44}

It is impossible to indicate or analyze the numerous elements that contributed to the period of hypotension in Case 1. The presence of the constrictive pericarditis with its peculiar physiologic effects undoubtedly influenced the metabolism of sodium and water and modified the classical picture of sodium depletion derived from human and animal experiments. Drugs, anesthesia, stress arising from the mental and physical trauma are but a few of the many factors affecting any patient under these circumstances. However, in the search for tangible evidence to explain why the young man reacted in an almost disastrous manner to the same operative procedure that the older man tolerated well it did not seem that the great difference in sodium metabolism could be ignored.

SUMMARY AND CONCLUSIONS

Metabolic studies have been conducted on two cases of pericardial resection for constrictive pericarditis. A comparison is made between the two in regard to the immediate postoperative course, which was benign in one and stormy in the other. An analysis of data obtained indicates that a preoperative

regimen of sodium restriction and withdrawal may be carried so far as to be deleterious. The following evidence is presented to support this view:

1. During the eight days of balance studies prior to operation, there occurred a cumulative deficit of 950 meq. of sodium (55 Gm. of salt), chiefly through aspiration of pleural fluid.

2. Hyponatremia (123.2 meq. per liter) occurred.

3. Total urinary sodium excretion for the seventy-two hours prior to operation was only 25 meq. despite the repeated use of a mercurial diuretic.

4. Hypotension developed while blood was being received and continued in spite of replacement of the estimated operative blood loss. Values for hematocrit and blood and plasma volume obtained during the period of hypotension did not indicate the presence of inadequately treated hemorrhage.

5. Hypotension and oliguria were overcome at about the time the sodium deficit was corrected.

In preparing cardiac patients for surgery the possibility of deleterious effects from sodium depletion following a limited salt intake and the abnormal loss of body fluids must be considered.

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DISCUSSION

DR. FRANK GERBODE, San Francisco.—Many of these patients who have been on a marked salt restriction diet for a long period of time have a very serious drop in serum

sodium on the second postoperative day, and it has been reported in some patients that when the sodium levels become very low, in addition to this hypotensive state which Dr. Crandell illustrated in one patient, there are also sometimes serious mental and central nervous system changes.

About one year ago, in collaboration with Dr. Quentin Deming, we embarked upon a program of giving these patients 3 Gm. of salt daily before, during, and after surgery, and in addition replacing all losses at surgery volume for volume, blood with blood, and serous fluid with saline solution; postoperative chest drainage and other nonrenal losses were replaced gram of salt for gram of salt with 0.9 per cent saline solution. No fluid other than this saline solution has been given except by mouth as the patient requested it. Since instituting this regimen we have not seen a serious fall in serum sodium concentration, and the patients appear to have been maintained in a better physiologic state. In no instance has there been pulmonary edema or precipitation of congestive failure by this treatment.

DR. GABRIEL P. SELEY, New York.—I want to congratulate Dr. Crandell on his careful analysis of these two cases, but I would like to point out that in addition to the metabolic changes it is rather risky to compare the two cases. I would like to ask him what was the situation locally; that is, how much constriction there was there, how much of the ventricles, both right and left, were involved, what the exact operative procedure was, and if he has any way of estimating what the musculature was like beneath the pericardium. I believe this information is important because certainly everyone has had the experience of doing a good resection and having a poor result, and doing a rather limited resection and having a rather good result.

DR. JOHANN L. EHRENHAFT, Iowa City.—In combination with the cardiovascular laboratory at the State University of Iowa we have studied three patients with constrictive pericarditis in an effort to demonstrate the significance of renal circulatory factors in edema formation in patients with this acquired cardiac disease. Pre- and postoperative studies were carried out. The renal plasma flow and glomerular filtration rates by standard plasma clearance methods were studied and we demonstrated a pattern of renal dysfunction identical with that of congestive myocardial decompensation. In two patients with marked hemodynamic abnormalities and massive edema, the renal dysfunction was severe. In one with mild hemodynamic aberration (associated with an interatrial septal defect) and no demonstrable edema, the renal abnormality was mild. All experienced spontaneous, diuretic weight loss in the early postoperative period. The two patients with marked weight loss of twenty-one and thirty pounds had an increase in the renal plasma flow of 84 and 80 per cent, respectively. The PAH values indicate normal tubular functional capacity in the two patients measured. Pericardiectomy was followed by modest increase in glomerular filtration rate and tremendous rise in renal plasma flow in the two patients with severe disability.

These changes probably are due to both the direct effects of restoration of hemodynamic factors toward normal, and the resultant indirect effects on neurogenic and humoral factors influencing renal water retention. Systemic venous and arterial pressure receptors may play an important role in the antidiuresis which characterizes the venous distention stage and the diuresis which occurs promptly following the postoperative increase in cardiac output and systemic arterial pressure. In the immediate postoperative period the sodium loss produced by the diuresis may be very marked, and those patients may develop signs of shock and need replacement of sodium, particularly if their reserve has been depleted by a low sodium intake in a preoperative effort to reduce edema.

DR. HARRISON BLACK, Boston.—Dr. Crandell's paper and his charts illustrate very nicely the exaggeration of electrolyte abnormalities which may become apparent postoperatively in patients undergoing cardiac operations. I believe there is one important factor, however, that has not been mentioned in this study or in the subsequent discussions, and that is the relationship between body sodium stores and the plasma sodium concentration.

At the Peter Bent Brigham Hospital we also have observed a considerable number of patients who have experienced a marked fall in serum sodium concentration after mitral valve surgery. Our lowest concentration with survival was 109 meq. per liter, and many have been found in the 120 to 125 range on the second postoperative day. The all-important factor which must be considered is the *total* amount of sodium in the body. This can be

measured by means of radioactive sodium dilution and the measurement discloses the "total exchangeable sodium" The total body water and total exchangeable potassium may also be measured and are equally important in interpretation.

Dr. Francis D. Moore and his associates, Drs Wilson and Myrden, at this hospital, have helped us a great deal by their isotope studies in cardiac patients. As they point out, a drop in serum sodium concentration may be due to one of three mechanisms: deficiency, dilution, or "shift" into cells We might discuss these separately.

Deficiency.—Despite the fact that many of these patients have been on a low sodium diet over long periods of time and have undergone repeated mercurial diuresis, they quite uniformly show a high total body sodium They also show a very high total body water. Indeed, this combination of a high sodium and a high water with a low serum sodium concentration is quite characteristic of the sick cardiac patient with or without edema and either before or after surgery. It is of great interest that a low total exchangeable potassium with a relatively high plasma potassium concentration is also a part of this picture, but we are not devoting attention to that in this brief discussion For this reason, we have felt that true sodium deficiency is rarely a part of this picture and, indeed, it does not seem logical to treat the patients pre or postoperatively with concentrated salt solution except under most exceptional circumstances.

Dilution.—The studies have shown in addition that cardiac patients when allowed unrestricted oral intake after surgery are extremely prone to gain body water. This is manifested clinically by gain in weight. It is apparent that even though no salt is given, these patients are still able to accumulate excessive body water and this, of course, may contribute further to the lowered serum sodium concentration It is of importance to note that during hot summer weather when skin and lung losses are higher, this tendency is not so apparent.

"Shift"—Although great care may be exerted to avoid extra water loading in these patients, they will still show some drop in serum sodium concentration. Dr Moore's group some years ago demonstrated that trauma itself tends to produce a lowering of the serum sodium concentration in the presence of a positive sodium balance, and they have felt that this is due to translocation or "shift" of sodium into cells There is recent evidence that in cardiac patients this tendency may be especially marked It should be emphasized also that intracellular water, newly appearing in the extracellular phase, might contribute to this appearance of "shift"

Before these studies were available to us, we too gave our postoperative cardiac patients hypertonic sodium chloride when a low serum sodium value was associated with the clinical features of the "low sodium syndrome" (that is, hypotension apathy, and disorientation) We were impressed with the fact that on many occasions this therapy was coincident with a rapid correction of the clinical aberrations and a rise in the serum sodium level. However, I am equally sure that in a few cases the salt load aggravated congestive failure with lethal outcome in at least one instance.

Taking all these factors into consideration we have modified our routine by restricting patients to 1,500 cc of fluid (oral plus parenteral), in the first twenty-four hours, not including in this the blood replacement On the second and third days the same amount is allowed and the ration is not increased until the usual spontaneous diuresis occurs In hot weather this figure will probably have to be increased With this method of management we have found that very few patients experience the severe drop of serum sodium concentration that we formerly saw, and the dangerous clinical features of the syndrome have become a thing of the past The result is that we have not found it necessary recently to use hypertonic salt solution Therefore, on the basis of these total balance studies, I believe we may conclude that the administration of saline solution to cardiac patients either preoperatively or postoperatively in the vast majority of instances is not rational and, in fact, may be dangerous.

DR K ALVIN MERENDINO, Seattle—The points which Dr Crandell brings out are certainly of great significance and I arise, as did Dr Black and Dr Gerbode, to broaden the implications or the points which have been made Following mitral commissurotomy, we unwittingly ran into a patient on the second postoperative day with hallucinations and apprehension The serum sodium was 118 meq and the chloride 69 meq This led us to

attempt to uncover the symptoms that would lead us to suspect this condition in other patients. Therefore my colleagues, Drs Robert Bruce, Marcelle Dunning, Belding Scribner, and I followed ten consecutive mitral commissurotomy patients with balance studies. No electrolyte of any kind was given during the postoperative period. However, the patients were allowed to take by mouth a formula of known composition. A negligible quantity usually was taken for the first three days. This gradually was increased.

(Slide) This shows the life history of this syndrome without any therapy whatsoever. These graphs represent the daily balance studies on these patients. The minimal, maximal, and mean responses are recorded. The serum sodium levels fell within the first two days postoperatively from an average of 142 meq to an average of 126 meq. Serum potassium revealed a slight rise; the chlorides fell to their lowest level the third day, a lag of twenty-four hours behind the sodium fall for some unknown reason. Electrolyte studies on the urine revealed a renal conservation of sodium as well as potassium during the same period. This was probably related to a low intake. The chloride changes were not significant.

(Slide) During the initial two or three day postoperative period, there is a positive water balance. The recorded output includes not only urinary output but a rough approximation of insensible loss. As you can see there is a positive water balance in extreme cases up to 2 L but on the average it is 850 cc.

(Slide) We have been able to catalog the severity of the patients' symptoms on the basis of the serum sodium levels. Seven of these eleven patients had symptoms. Those with moderate symptoms had sodium levels of 120 to 130 meq. Those with severe symptoms had sodium levels of 111 to 120 meq. As long as the serum sodium remained about 120 meq the symptoms were not severe.

(Slide) These are the symptoms encountered in this group of patients. In the moderate group, asthenia, lethargy, anorexia, and variable sweating were observed. The severe group had cerebral disturbances which included apprehension, hallucinations, and delirium, even to the point of coma.

(Slide) In our opinion these are the contributing factors, some of which have been mentioned by Dr Crandell and the other discussers, namely, preoperative salt depletion, salt deprivation postoperatively, the administration of a nonelectrolyte containing fluid, non-specific stress response, and pleural drainage which contains on an average of 66 meq for the first one to four days postoperatively but may be as high as 160 meq. It appears that no single factor is sufficient to produce the hyponatremic levels observed. All factors are participating in a greater or lesser degree in each individual patient, as well as other factors incompletely understood at present.

(Slide) In the next fourteen consecutive mitral commissurotomies we conducted a prophylactic program. All patients on the day of surgery and daily thereafter were given 73 meq. of sodium (500 cc saline solution). This was supplemented with additional saline as indicated by the serum sodium levels. Some patients have received as much as 20 Gm of sodium chloride in one day. No attempt was made, however, to restore the serum sodium to normal levels in the early postoperative period. From the practical point of view, other things being equal, the serum sodium level is the most important single laboratory procedure in the management of cardiac patients following surgery. In this fashion, we have been able to prevent the extreme degrees of hyponatremia and the severe symptoms and signs associated with it.

DR CRANDELL (Closing) —Time would not permit answering Dr Seley's questions. I will try to answer them indirectly in this fashion. You will recall that the young man, aged 27 years, had a poor immediate postoperative response and the older man, aged 54 years, had a good response. Although the young man immediately entered a stormy period, he has ultimately had an excellent result, to the extent that two years after the pericardial resection he was able to carry a 150 pound deer two miles out of the woods without any trouble. On the other hand, the older man has experienced a considerable limitation of activity.

I am very grateful to Dr. Gerbode for his discussion, and to Dr. Black, who has helped provide answers to questions about which we are curious. I certainly envy his facilities in having available radiosodium and deuterium oxide. I wish to thank Dr. Merandino for his discussion.

BRONCHIAL CLOSURE IN PULMONARY RESECTION: A CLINICAL AND EXPERIMENTAL STUDY USING A PEDICLED PERICARDIAL FAT GRAFT REINFORCEMENT

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INTRODUCTION

PERMANENT bronchial closure is the basis of a successful pulmonary resection. Current methods are generally quite effectual when the bronchus is normal, although a wide variation in results is reported. However, when the bronchial wall is diseased and friable and the stitches fail to hold, surgeons agree that there is an urgent need for an occlusive reinforcing tissue. A highly effectual method of developing a viable, pedicled pericardial fat graft reinforcement to the bronchial stump was devised by one of us (L. A. B.) in July, 1949, after trying pleura and other tissues. Our technique of closing the bronchus and of developing the graft is presented, along with pertinent data concerning clinical and experimental observation. A review of 323 cases of total pneumonectomy and lobectomy for malignant and nonmalignant disease is made. The superiority of this method, in our experience, is shown by comparing the results with this technique in 221 cases, to those of an earlier series of 102 cases in which the "thoracic omentum" was not used.

HISTORICAL DATA

With the risk of oversimplification, we have divided the history of pulmonary resection and bronchial closure into four definite periods, in order to condense an extensive review.

1. Period of "fortuitous" pulmonary resection (1496 to 1880, and even later).
2. Period of animal experimentation (1880 to 1900).
3. Beginning modern period (1890 to 1928).
4. Present-day period (1929 to the present time).

1. *Period of "Fortuitous" Pulmonary Resection.*—Before the understanding of pulmonary and intrathoracic physiology had been developed (latter part of nineteenth, and early twentieth centuries), a few intrepid surgeons were successful in excising relatively small amounts of peripheral pulmonary tissue, aided by the fortuitous fusion of the pleura and a fixed mediastinum. Since these early successes in the removal of pulmonary tissue have almost completely escaped notice in the medical literature, we are including a brief description of the three earliest pulmonary resections that we have been able to discover.

The first recorded excision of lung tissue was reported by an Italian, Rolando of Parma,¹ in 1496. He was called to treat a man of Bologna who had

¹Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 30, 1953.

suffered a severe wound of the thorax, in which the lung was protruding on the chest wall. The patient had been given up by other surgeons, and on the sixth day after the wounding, the lung presented as a mortified, gangrenous tissue. Rolando excised this lung tissue, and to his amazement the wound healed, aided no doubt by the beneficial débridement of maggots. Since this excision of lung tissue was in complete violation of all the surgical precepts of the age, Rolando was happy to report that the man was perfectly well one year later and able to make a trip with his master to Jerusalem.

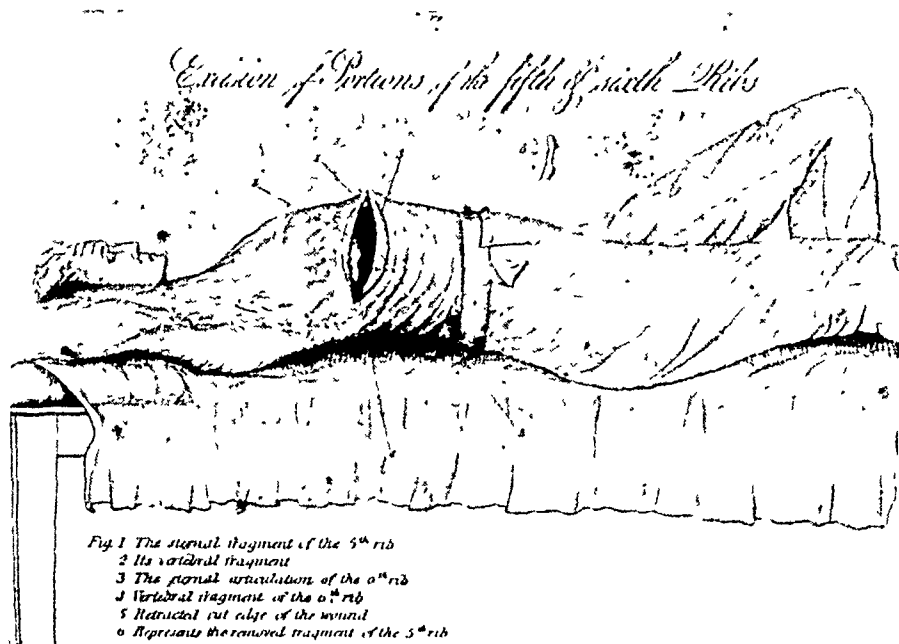


Fig. 1 —Drawing of the thoracotomy incision reported by Milton Anthony of Augusta, Ga., in 1821. Published in *The Philadelphia Journal of the Medical Sciences* in 1823.

This surgical feat was unknown for centuries, and it remained for an American pioneer, Milton Anthony,² in Augusta, Ga., to record the first deliberate entrance of the pleural cavity in 1821 and the removal of "one to two pounds" of pulmonary tissue, along with the portions of two ribs. The man he treated had a swelling in the thorax which came on approximately one year after an injury to the chest. The tumor of the chest wall was incised and sections of the fifth and sixth ribs were excised, along with portions of necrotic lung tissue. The exact nature of the pathology was not known although it could have been a neoplasm of the chest wall and lung or some sort of chronic inflammatory process. However, after the thorax had been opened, to Anthony's "utter astonishment and mortification," he was able to palpate "more or less disorganized fragments of bronchial tubes." He then guided the hand of his intrepid assistant, Dr. Pugsley, "an aged, experienced and accurate surgeon and anatomist" into the chest to feel the extensive destruction of the right lung. Anthony, a compassionate man, did not wish to discuss out loud

this shocking finding, in order not to "alarm" his conscious, but stoical patient. The man recovered from the surgery to succumb at a distant hamlet one year later. Fig. 1 is a reproduction of the incision used by Anthony in his published report in 1823.

In 1861, Jules Emile Pean,³ a Parisian, apparently with the benefit of general anesthesia, excised a pulmonary tumor and portion of the lung. The patient had a small tumor at the level of the fourth intercostal space, which caused him severe and intolerable pain. After aspiration of the tumor yielded no fluid, an exploratory incision was made. To Pean's surprise a tumor arising in the lung adherent to the pleura was found. The tumor was drawn out, after having effected adherence of the parietal and visceral pleura at a number of points by interrupted sutures. The tumor was then excised by galvanocautery. Hemostasis was further effected by leaving on several hemostats and by "Phoenician" dressing. The patient was apparently cured by this operation and was reported in good health one year thereafter. Since Pean had the insight to sew the two layers of the pleura together, this case was not as "fortuitous" as the others. However, from the point of view of bronchial closure, only peripheral lung tissue was excised and no bronchus of moment was divided. Thus, bronchial closure had not yet become a problem in pulmonary resection.

2. *Period of Animal Experimentation (1880 to 1900).*—Because of the general use of anesthesia and the discovery of microorganisms and antiseptics, many techniques for abdominal operations were perfected during the latter quarter of the nineteenth century. Faced with the disasters in opening the thorax of human beings, a few surgeons, notably German, turned to the experimental laboratory to study suitable methods of lung excision. The Germans, Gluck,⁴ Schmid,⁵ Block⁶; the Italian, Biondi⁷; the Englishman, Willard⁸; the Americans, LeMoyne Wills⁹ of Los Angeles, and Murphy¹⁰ of Chicago performed pulmonary resections on experimental animals. Murphy made the important observation that if the mediastinum was fixed, the pleural cavity could be opened without severe anoxia, but if the mediastinum was mobile, anoxia and death resulted. These experiments shed light upon the problems of open pneumothorax and mediastinal shift and resulted in the cautious, but realistic attitude of the clinical surgeons. They showed, moreover, that lobes and lungs could be resected but that a high mortality resulted. Mass ligation of the structures at the hilum was the technique that ushered in the early modern period of pulmonary resection. Bronchial fistulas were almost invariably present in the animals surviving the operative shock and sepsis. Broncho-pleural fistula was recognized as a hazardous and almost inevitable complication of pulmonary resection.

3. *Beginning Modern Period (1890 to 1928).*—Stimulated by experimentation, Tuffier,¹¹ in 1891, resected the apex of the lung affected by localized tuberculous disease. He used an extrapleural approach and closed the wound

without drainage. The patient made an uneventful recovery and was well and working four years after the operation. In 1901, Heidenhain¹² performed a successful lobectomy for bronchiectasis.

The problem of open pneumothorax continued to vex the surgeon despite the experimental work of the preceding period. Sauerbruch,¹³ in 1904, introduced his "reduced pressure operating cabinet" which sought to obviate this difficulty. The patient and the surgeon were placed in a roomlike cabinet in which the pressure was reduced by 18 to 20 mm. of mercury. The patient's neck and head extended out of the cabinet. An airtight seal was made about the neck. Thus, the patient could breathe in room air and the collapse of the lung was counteracted by the negative pressure. In 1908, in this country, Willy Meyer¹⁴ perfected a positive pressure cabinet. This cabinet was placed about the head of the patient and was large enough to accommodate the anesthetist. Positive pressure in the cabinet from 20 to 25 mm. of mercury protected the lung from collapse when the thorax was open.

During the first decade of the twentieth century, work on endotracheal anesthesia continued. Following the efforts of Tuffer, Matas¹⁵ and others, Elsberg¹⁶ reported endotracheal insufflation anesthesia with a positive pressure of 20 mm. of mercury. This technique was further developed and popularized by McGill¹⁷ in the 1920's. And endotracheal anesthesia became the standard form of anesthesia for intrathoracic operations. It was used by Lillienthal¹⁸ in the majority of the twenty-two lobectomies with a 42 per cent mortality that he reported in 1922. However, he regarded the positive pressure chamber as being useful in cases "in which it was desirable to keep the thoracic wound open for a few hours or even days after the operation." The high mortality with lobectomy stimulated Graham¹⁹ to develop the procedure of cautery pneumonectomy, which he reported in 1923. The actual destruction of the bronchiectatic lung tissue by the cautery method resulted in a relief of the patient's symptoms, with a lessened mortality. In reviewing the advances of this period, we are impressed by the fact that it was now possible to open the thorax and remove lung tissue, even entire lobes of the lungs, aided by endotracheal anesthesia. The bronchial stump in pulmonary lobectomy was still controlled by mass hilar ligation. Bronchial fistulas were the expected complications of lobectomy, as an anatomic approach to the closure of the bronchus had not yet been perfected, and successful pneumonectomy in human beings was still an unsolved problem.

4. *Present-Day Period (1928 to Present Time).*—Brunn,²⁰ in 1929, reported the technique for one-stage lobectomy which may be regarded as ushering in the present-day period of pulmonary resection. He presented six cases in which lobectomy was performed with one operative death. The pedicle of the lobe was clamped and double, interlocking chromic catgut sutures were tied to control the vessels and the bronchus. The pedicle was then closed over with a running stitch of chromic catgut.

In 1932, Shenstone and Janes²¹ reported the technique of tourniquet lobectomy. The use of a tourniquet made the operation considerably safer and

the size of the lobar stump was smaller. This technique was quite generally accepted until the beginning of World War II. In 1931, Nissen²² performed a two-stage pneumonectomy for bronchiectasis with mass ligation of the hilum. The lung was allowed to slough off. In 1932, Haight²³ also reported a successful two-stage pneumonectomy. The year 1933 will be remembered for the first successful one-stage pneumonectomy for carcinoma, performed by Graham.²⁴ Resection of the lung by one-stage procedure had now become feasible and new impetus was given to pulmonary resection.

Shortly after this, Rienhoff²⁵ introduced a method of individual ligation technique for the hilar structures in pneumonectomy. The technique, with some modifications, is in use today. In 1939, Churchill and Belsey²⁶ reported the individual ligation of the lobar and segmental vessels and bronchus with segmental pneumonectomy of the lingular segments of the left upper lobe for bronchiectasis. Kent and Blades,²⁷ in 1942, reported the sound anatomic approach to pulmonary resection by the individual ligation of the vessels and bronchus for the respective lobes of the lung. At last precise surgical technique had been developed and no longer were bronchial fistulas accepted as the inevitable complications of lobectomy or pneumonectomy.



Fig. 2.

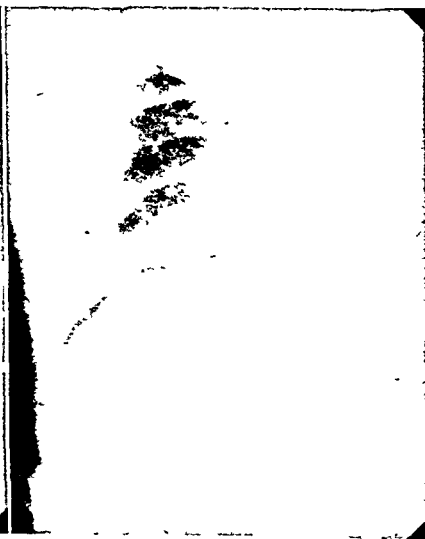


Fig. 3

Fig. 2 (Case 1) —Preoperative chest X-ray film shows total atelectasis of the left lung, which was caused by an adenoma obstructing the left main bronchus

Fig. 3 (Case 1) —X-ray view of chest, one year following total pneumonectomy. The severed bronchus leaked air following pneumonectomy. It was successfully closed with a pedicled pericardial fat graft.

AUTHORS' MATERIAL

Our technique of employing pericardial fat graft to reinforce the bronchial stump was born out of sheer desperation in a case where we were unable to close securely a diseased bronchus. Fig. 2, the preoperative film of this case, shows a benign adenoma of the left main bronchus which had produced

total atelectasis of the left lung. The patient had had a chronic cough for years, and there was considerable bronchitis in the portion of the bronchus above the tumor, in the vicinity of the carina. On July 1, 1949, while resecting the left lung which had been destroyed by the protracted bronchial obstruction, great difficulty was encountered by one of us (L. A. B.) in effecting closure of the diseased bronchial wall at the carina. However, an airtight suture of the bronchus was effected and the chest wall was closed. Immediately following the operation, on hard coughing, it was obvious that the bronchus had re-opened. The chest was again entered and the torn bronchus noted. Further attempts to close this tear resulted in extension of the rent up into the tracheal wall. Borrowing from the experience in surgery of the abdomen, where omentum has been successfully used for years to seal off the repair of a ruptured peptic ulcer, it was decided that a pedicled pericardial fat graft, in a similar manner, might seal off the aperture in the bronchial and tracheal walls. Such a graft was fashioned and sutured to the incompletely closed bronchial stump and trachea. The closure remained airtight, and the patient made an uneventful recovery. Fig. 3 shows the film one year following surgery.

Following this gratifying result we decided to investigate this technique further on experimental animals.

EXPERIMENTAL OBSERVATIONS

In a series of twenty-one mongrel dogs, pedicled pericardial fat grafts were developed for bronchial reinforcement in either total pneumonectomy or lobectomy. To simulate the conditions of our original case, the bronchial stump was incompletely closed so that there was a definite blowing of air on application of positive pressure to the bronchial stump following the pulmonary resection. A pedicled, pericardial fat graft was then developed, usually from the middle portion of the mediastinum and firmly fixed to the bronchial stump, according to the technique to be described for human beings later in this communication.

We experienced some difficulty in developing these grafts for two reasons: First, the pericardial adipose tissue was extremely thin and friable and did not exhibit as satisfactory a blood supply as that found in human beings, and great care had to be exercised in developing the grafts so as not to tear the very fragile mediastinal pleural septum and enter the opposite pleural space. That this septum exists as an effective barrier between the pleural spaces is much disputed; however, our experience along with that of many others points to the presence of this septum as a fragile but definite barrier between the two pleural cavities. We are pleased to note that *the grafts effectively closed the bronchi and prevented the dogs from developing bronchial fistulas and empyema in all instances*. It should be emphasized, however, that these dogs were all given penicillin for three or four days following operation. It is also true that the bronchi were apparently grossly normal in all instances. In our experience, lobectomy and pneumonectomy in dogs protected by antibiotics, with or without the grafts, have a very low rate of bronchial fistula.

The cartilage of the dog's bronchus is so flexible that it is not necessary to make an elliptical flap of the membranous portion of the bronchus, as we routinely do for major bronchi in human beings. After performing five pneumonectomies, we performed lobectomies on subsequent animals as it was apparent that we could study the viability and fate of the graft just as well. Furthermore, following the lobectomy, the animal was available for other intrathoracic procedures (most of them cardiovascular), which were performed on the same and, in some instances, on the opposite side of the chest.

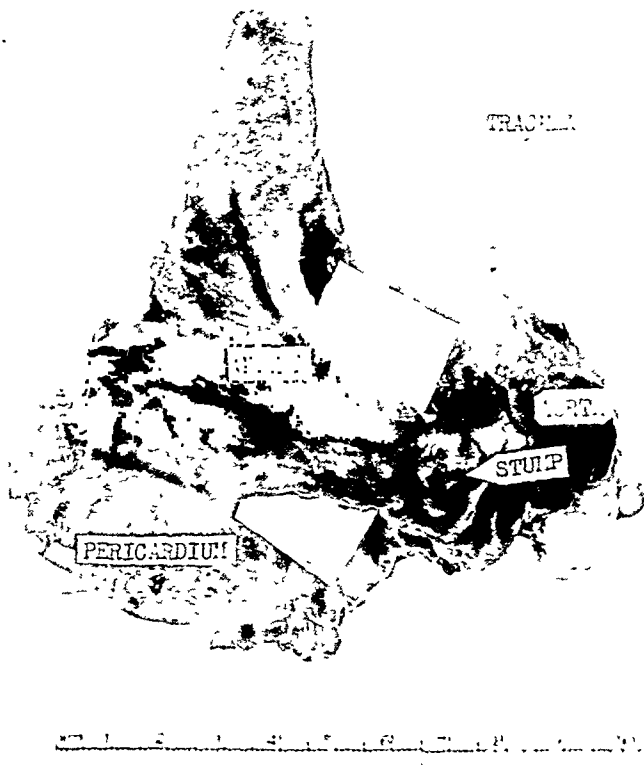


Fig. 4.—Dog 3-D. Gross specimen of pedicled pericardial fat graft covering bronchial stump three days after left total pneumonectomy had been performed. Specimen shows the pedicled graft firmly in place, tightly reinforcing the bronchial stump.

In all cases, when observed at autopsy, or at subsequent operations, the grafts were intact and appeared to be grossly viable and firmly fixed to the bronchial stump. The maximum period of observation was one year.

Microscopic studies were made upon the grafts from periods of twenty-four hours up to one year. The suture material had to be picked out of the blocks before they were cut and this practically always frayed the sections. In twenty-four hours, the graft was adherent to the bronchus, the fat cells were intact, and a leukocyte infiltration was present. By three days (Figs. 4, 5, and 6) the leukocyte infiltration had increased, some edema fluid was

present, and fibroblastic proliferation was noted, uniting the bronchus and fat graft. By the eighth day (Figs. 7, 8, 9, and 10) fibroblasts had increased in the zone of tissue that marks the junction of the pericardial fat graft and the cut ends of the bronchus. Columnar epithelium had bridged over the fat graft.



Fig. 5.—Dog 3-D Low-power view of sagittal section of bronchial stump three days after left total pneumonectomy. The pedicled pericardial fat graft appears in the lower center of the field, covering the incompletely closed bronchial stump. Although the section is torn, the beginning fibrous union of fat graft and bronchus can be seen.

Further out in the fat graft, irregular areas of fibroblastic proliferation and all the early signs of organization were present. Macrophages with hemosiderin represented the phagocytosis of hemoglobin from operative hemorrhage. After one month's time or more, adult type of fibrous tissue was present in the part of the fat graft next to the bronchus with irregular involvement of more peripheral portions of the graft. In four months' time (Fig. 11) the fibrosis was perhaps a little more advanced, otherwise there was very little change up to one year's time. No further fibrosis of the fat graft was noted after this. Intact fat cells were present and the vascularity of the graft was evidenced by the finding of small blood vessels in all sections.

Our findings are similar in some ways to the experimental observations on dogs made by Rienhoff.²⁵ He reported that there was a marked tendency in dogs to bridge over defects in bronchial closure by proliferation of submucosal and peribronchial tissue, together with granulation tissue derived from the nonserous surface of a mediastinal pleural graft. In our experiments, the viable pericardial fat graft was used in place of pleura. We did not notice the great tendency for the bronchial walls to separate at the site of closure that he reported. Perhaps, the pericardial fat graft helped to hold the bronchus together. The microscopic study of the bronchial stumps, reinforced with the pericardial fat grafts, confirmed the gross observations of the effectiveness of these grafts as a bronchial reinforcement. The grafts are truly linked to the bronchial stump by a fibrous union.



Fig 6—Dog 3-D High-power view of sagittal section of bronchial stump seen in Fig. 5. Viable adipose tissue blocks the opening between the two cartilages. Early fibroblastic proliferation has begun. Epithelium has not regenerated.

TECHNIQUE OF BRONCHIAL CLOSURE

In closing the main bronchus we used a simple interrupted suture, bringing the soft membranous portion of the bronchus to the fixed cartilaginous wall. To effect this closure without tension, a slightly oval-shaped flap is cut from the posterior membranous portion of the bronchus, so that it would meet the more rigid cartilaginous wall. No clamps are placed on the bronchus at the site of suture and an "open" type of closure is used. The bronchial arteries are carefully preserved. With lobar bronchi, the closure is more easily

Fig. 7.

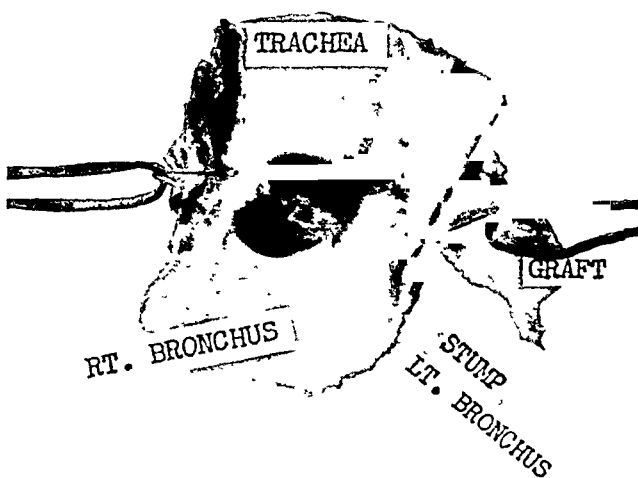
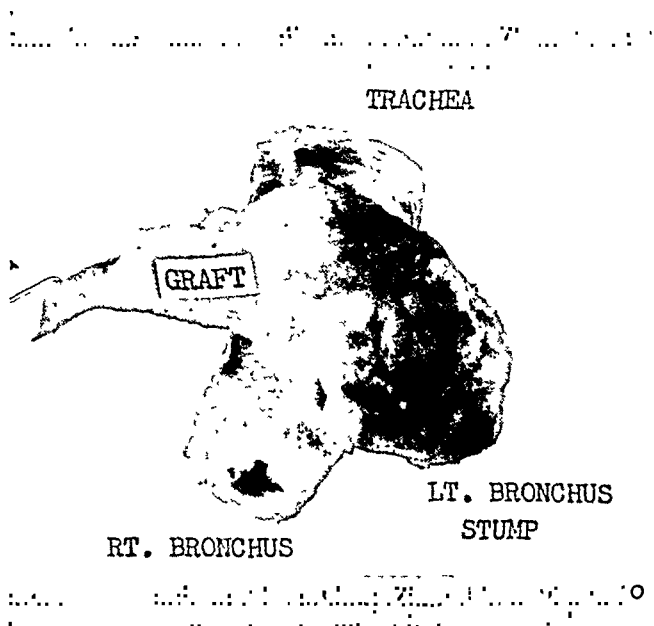


Fig. 8.

Fig. 7.—Dog 165. Gross specimen of left bronchial stump eight days after total pneumonectomy. Graft firmly adherent to the bronchial stump.

Fig. 8.—Dog 165. Gross specimen of inside of left bronchial stump eight days after pneumonectomy. Complete epithelization of incompletely closed bronchus is seen.

Fig. 9.



Fig. 10.

Fig. 9.—Dog 165. Low-power view of sagittal section of bronchial stump eight days after pneumonectomy shown in Figs. 7 and 8. Fat graft occupies lower portion of section. Fibrous union with bronchial wall is seen.

Fig. 10.—Dog 165. Medium-power view of sagittal section of bronchial stump. Fat graft fills in aperture between two cartilages. Fibrous tissue and cellular infiltration are present. Epithelium has bridged the gap in the mucosa.

effected, since the cartilage is softer and the walls usually collapse without tension on a simple right-angled division of the bronchial wall. The formation of the cartilage may be irregular and completely surround the bronchus, leaving no posterior membranous wall. However, in many instances the anatomy of the lobar bronchus resembles that of the main bronchus.

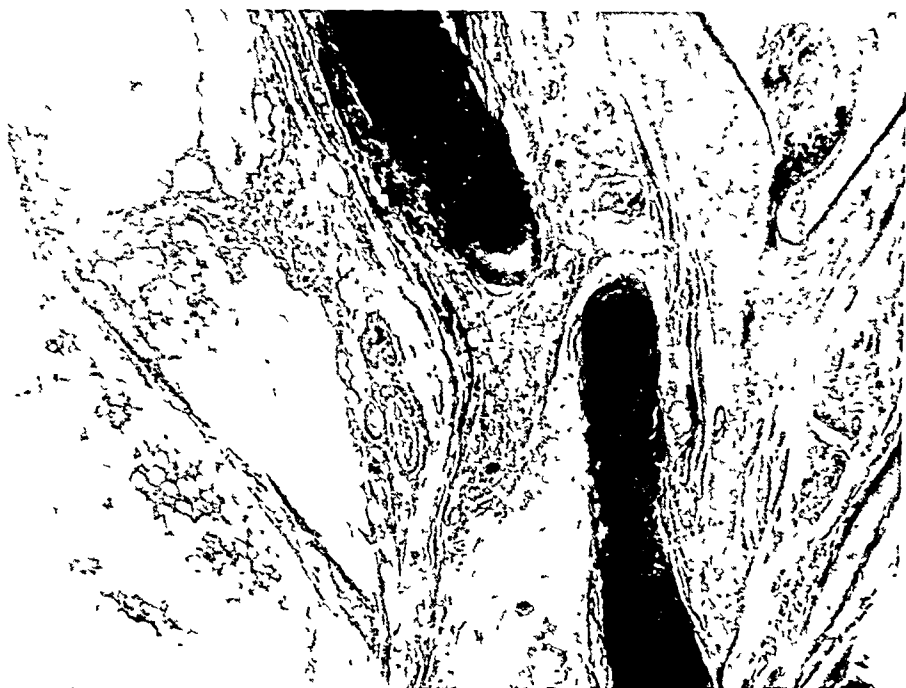


Fig. 11—Dog 121 Medium-power view of microscopic section of bronchial stump four months after lobectomy. Fat graft is shown to be viable, and fixed to bronchial wall by adult connective tissue which is also present deeper in the graft. Note the blood vessels in the graft.

The exact technique of the bronchial closure of a main bronchus is shown in Fig. 12. For suture material, we have used tantalum wire, 0.007 inch in diameter onto which a fine needle has been tightly swedged. The diameter of the needle is approximately the same as that of the wire, and thus it does not make a hole in the bronchial wall that may eventually leak. Care is taken to cut the cartilaginous wall along the upper edge of the cartilage, leaving 1 to 2 mm. of membranous wall behind, if possible, which is more suitable for the bronchial closure. The wire sutures are tied just tightly enough to approximate the walls of the bronchi so that there is no leakage. If the wire sutures are tied too tightly they will cut through the bronchus. The cut ends of the wire are turned in so as not to sever any of the major vessels of the hilum. The graft offers further protection to the wire ends. However, on upper lobe branch bronchi we have routinely used fine arterial silk, fearing erosion of the pulmonary artery from the ends of the wires may otherwise result.

DEVELOPMENT OF VIABLE PERICARDIAL FAT GRAFT

The anatomy of the mediastinum and the pericardial fat is depicted on the diagram (Fig. 13). The fatty tissue in the pericardium and the anterior mediastinum receives its blood supply mainly from branches of the internal mammary artery. However, branches of the pericardiophrenic and musculophrenic arteries also send nutrient branches to this fatty tissue. The pericardiophrenic artery accompanies the phrenic nerve between the pleura and the pericardium to the diaphragm, where it anastomoses with the musculophrenic and inferior phrenic arteries. The anterior mediastinal branches of the internal mammary artery supply the areolar and adipose tissue in the anterior mediastinum, along with the remains of the thymus. The main pericardial branches of the internal mammary artery are two in number: a superior branch to the superior

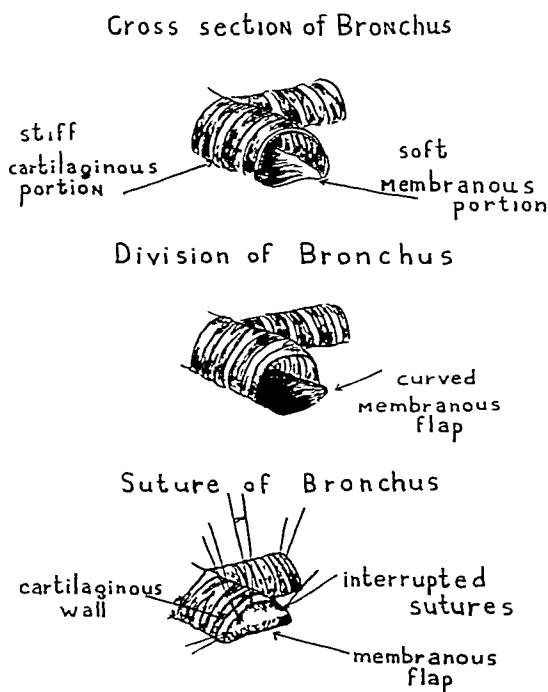


Fig. 12.—Technique of closure of the bronchus used by us.

pericardium, and a middle branch to the midportion of the pericardium. This middle branch is a fairly large and constant vessel and is the one that supplies the blood to the graft in the great majority of instances. The inferior pericardial branch comes from the musculophrenic branch of the internal mammary artery.

The anterior mediastinal, pericardial, and sternal branches, together with some twigs from the pericardial phrenic artery, anastomose with branches from the intercostal and bronchial arteries to form the subpleural mediastinal plexus.²⁹ The veins draining this plexus are less uniform in their course than

are the arteries, but they tend to follow the arteries. It is from the branches of this plexus, some of which may not be readily visible to the naked eye, that the blood supply of the pericardial fat graft is maintained, even though a fairly long pedicle is developed. There may be considerable variation in the course of the branches of the internal mammary arteries that supply the adipose tissue; however, with a careful inspection of these branches the graft may be so planned as to include a satisfactory blood supply in over 95 per cent of the cases.

Lateral View of Anatomy of Right Side of Mediastinum

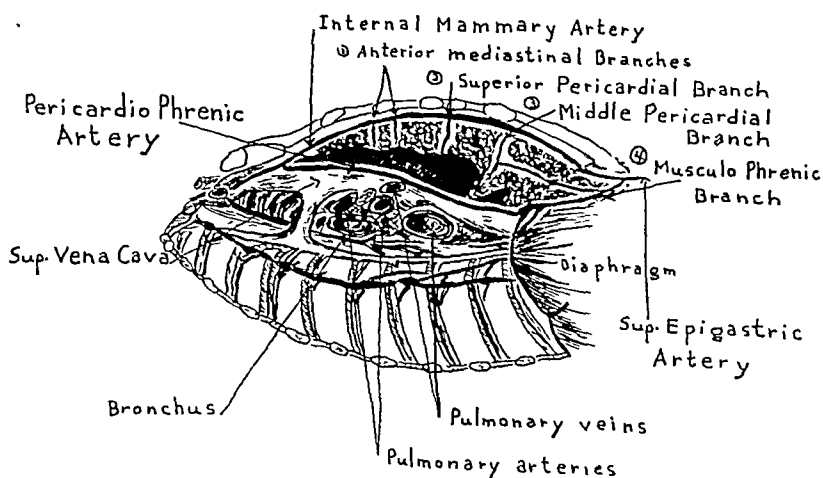


Fig. 13.—Diagram of anatomy of right side of mediastinum, showing the blood supply to the pericardial and mediastinal adipose tissue.

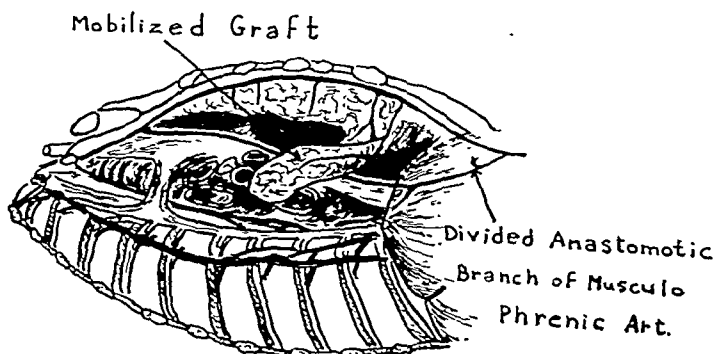
We have found that the most satisfactory pericardial fat graft can be developed from the anterior inferior mediastinum, utilizing the adipose tissue that lies directly over the diaphragm. The blood supply to this portion of the pericardial fat comes from the musculophrenic artery, the middle pericardial branch of the internal mammary artery, and a few twigs from the pericardiophrenic vessels. There is a fairly constant branch that connects the middle pericardial branch of the internal mammary artery and the musculophrenic artery which, when present, provides an excellent blood supply to the mobilized graft, after the division of the branches of the musculophrenic and pericardiophrenic arteries. Because the pericardial fat extends for a distance anteriorly to cover the anterior surface of the heart, satisfactory lengths of the graft may be obtained. The blood supply is entirely from the vessels mentioned, and there are no vessels of any moment running down the mediastinum mesial to the internal mammary artery. In the case of a middle or lower lobe lobectomy, no difficulty at all is encountered in obtaining satisfactory length of the graft. However, in an upper lobe lobectomy, or pneumonectomy, con-

siderable care must be exercised in preserving the blood supply to obtain a satisfactorily viable graft. The freeing up of the graft is shown in Fig. 14. In some instances it may be necessary to divide the internal mammary artery below the junction of the middle pericardial branch, ligate the perforating intercostal and sternal branches, and dissect the internal mammary artery upward so as to obtain additional length of graft with adequate blood supply. However, with a little care and practice, the graft is readily developed.

Four sutures are then placed at equal intervals on the circumference of the bronchial stump. With the tip of the graft turned back, the mesial and

Fig. 14.

Development of Inferior Pericardial Fat Graft



Suture of Graft to Bronchial Stump

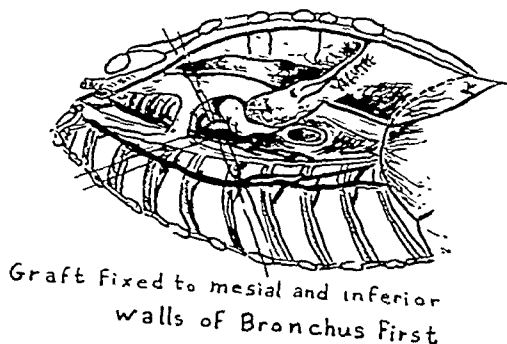


Fig. 15.

Fig. 14.—The inferior pericardial fat graft is developed by dividing anastomotic branch of musculophrenic artery and the pericardiophrenic branches.
 Fig. 15.—Graft sutured to bronchial stump by interrupted sutures.

inferior sutures are sewn to the graft and tied first (Fig. 15). Then, the superior and lateral sutures are affixed to the graft so that it fits over the stump of the bronchus, like a cap. Additional interrupted sutures of fine silk are now placed in the tissue about the bronchus to fix the graft firmly in place and make the reinforcement airtight (Fig. 16). The graft is further firmly sutured to the mediastinum and pericardium to take the tension off the bronchial stump on coughing and invite early union of the graft to these structures.

Fixation of Graft to Mediastinum

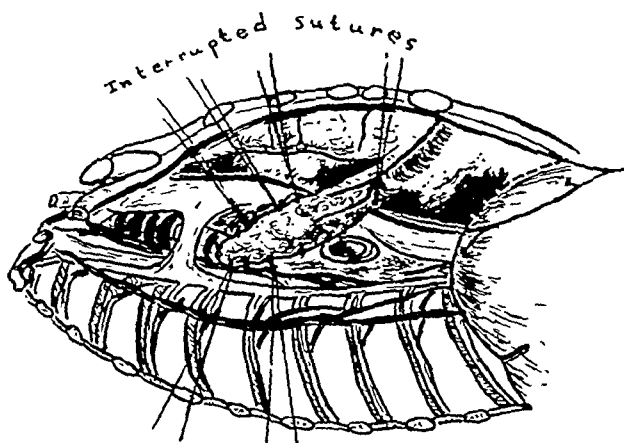


Fig. 16.—Graft is firmly fixed to the mediastinum.

Two alternate methods of developing a fat graft are available at times when the one described is not feasible. There is always a certain amount of adipose tissue that accompanies the phrenic nerve and the pericardiophrenic vessels. If it is desirable to sacrifice the phrenic nerve, then the nerve and the pericardiophrenic vessels and adipose tissue may be divided just above the diaphragm, and these structures are carefully teased off the pericardium and developed as a graft which is fixed to the bronchial stump in the previously described manner (Fig. 17).

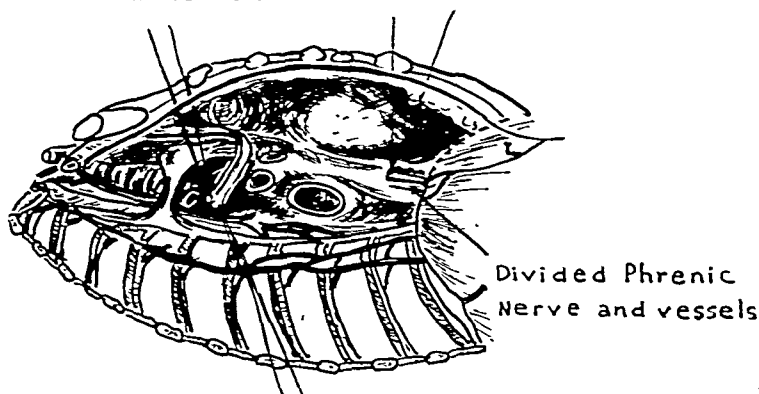
In some instances, the scantiness of free adipose tissue accompanying the nerve and vessels makes this graft unsatisfactory. Another form of anterior mediastinal fat tissue graft, though not strictly pericardial, may be developed from the adipose tissue in the anterior superior mediastinum where the blood supply comes mainly from the anterior mediastinal vessels and the superior pericardial branches of the internal mammary artery. Here the blood supply is not usually as good as that of the inferior pericardium; however, a shorter pedicle needs to be developed as the distance from the anterior superior mediastinum to the main-stem bronchus or the upper lobe bronchus is less than that

from the inferior mediastinum. We have used this type of graft in a small number of cases. The technique of application is shown on Fig. 18. It should be added that in the case of the inferior pericardial fat graft in which the middle pericardial branch of the internal mammary is used for the blood supply, the graft serves to form a sling reinforcement to the heart when the pericardium has been resected for an intrapericardial ligation of the pulmonary vessels in the case of a hilar carcinoma. Sometimes it is possible to fix the graft to the edges of the opened pericardium and thus prevent herniation of the heart, which, unless it is immediately relieved, is usually a fatal complication.

Fig. 17.

Alternate Methods

I. Pericardio Phrenic Graft



II. Anterior Superior Mediastinal Graft

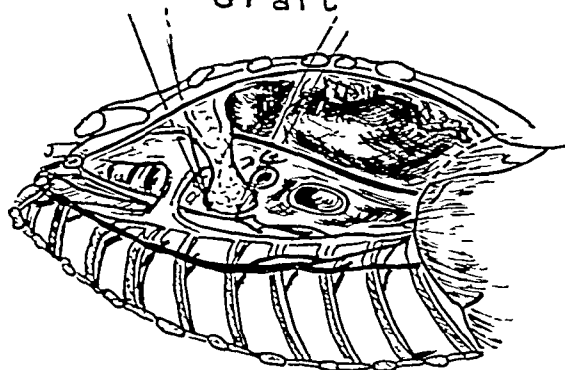


Fig. 18.

Fig. 17.—Adipose tissue accompanying the phrenic nerve is supplied by the pericardio-phrenic vessels. When phrenic nerve can be sacrificed, this provides an alternate method of bronchial stump reinforcement.

Fig. 18.—Anterior mediastinal branches of the internal mammary artery supply adipose tissue in anterior mediastinum suitable for bronchial stump reinforcement.

TABLE I. TOTAL PNEUMONECTOMY AND LOBECTOMY IN PERICARDIAL FAT GRAFT SERIES
(JULY, 1949, TO FEBRUARY, 1953)
221 CASES

	PNEUMONECTOMY	LOBECTOMY
Carcinoma	89	9
Pulmonary tuberculosis	20	32
Bronchiectasis	9	40
Lung abscess	0	21
Bronchial adenoma	0	1
Total	118	103

CLINICAL RESULTS

In all, 323 cases of either total pneumonectomy or lobectomy were reviewed to determine the effectiveness of the bronchial closure and the pericardial fat graft. In 221 cases, the technique outlined with the pericardial fat graft reinforcement was employed (Table I). While in 102 cases no pericardial fat graft was used (Table II). We believe these two series are very comparable because all the operations were performed by one of us (L. A. B.) with the exception of a few cases, so that the technique was the same in the two series, except for the application of the fat graft in one instance and the use of some other form of reinforcement in the other.

TABLE II. TOTAL PNEUMONECTOMY AND LOBECTOMY IN PREPERICARDIAL FAT GRAFT SERIES
(JULY, 1946, TO JUNE, 1949)
102 CASES

	PNEUMONECTOMY	LOBECTOMY
Carcinoma	26	8
Pulmonary tuberculosis	8	3
Bronchiectasis	5	26
Lung abscess	3	14
Bronchial adenoma	4	5
Total	46	56

The results of these techniques are compared on Table III. It will be noted that the incidence of bronchial fistula in the prefat graft series was 7.9 per cent, almost one-half of these occurring in the first two weeks; while in the larger series of cases in which the fat graft was employed, there were no bronchial fistulas occurring in the early, critical first three weeks. In this series a late occurrence of bronchial fistulas, up to five months after operation, was 2.5 per cent. It is further noted that bronchial fistula was the main cause of death in three of the earlier cases (Table IV). Thus, it is apparent that

TABLE III. COMPARISON OF RESULTS PRE- AND POSTPERICARDIAL FAT GRAFT REINFORCEMENT.
INCIDENCE OF BRONCHIAL FISTULA

	WITHOUT GRAFTS (102 CASES)		WITH GRAFTS (221 CASES)	
	Early First 3 weeks	Late Fourth week plus	Early First 3 weeks	Late Fourth week to fifth month
Pneumonectomy	5	1	0	5
Lobectomy	0	2	0	1
Total	5	3 = 8 (7.9%)	0	6 = (2.7%)

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DISCUSSION

We have seen how the individual ligation technique for hilar structures for pneumonectomy,¹⁴ lobectomy,¹⁵ and segmental lobectomy¹⁶ placed pulmonary resection on a sound anatomic basis. In closing the divided main bronchus following pneumonectomy, Rienhoff¹⁷ first cut the cartilaginous rings of the bronchial stump at various points in their circumference in order to do away with a springlike action, which normally tends to maintain the



TABLE VI. POST-MORTEM FINDINGS IN PULMONARY RESECTIONS WITH PEDICLE PERICARDIAL FAT GRAFT REINFORCEMENT OF BRONCHIAL STUMP

CASE	AGE	DIAGNOSIS	OPERATION	CAUSE OF DEATH	P.O. DAY	PATHOLOGIC FINDINGS
II.	72	Carcinoma	Pneumonec- tomy	Cardiac failure Pulmonary edema	1	Graft covers stump. No reaction to graft
N. G.	43	Pulmonary tu- berculosis	Lobectomy	Pulmonary em- bolus	2	Graft fixed to stump. Leukocytic infiltra- tion
J. V.	33	Pulmonary tu- berculosis	Pneumonec- tomy	Tuberculous pneumonia	10	Graft firmly adher- ent. Leukocytic and fibroblastic in- filtration of graft union
S.	51	Carcinoma	Pneumonec- tomy	Bronchopneu- monia	17	Graft firmly fixed by adult connective tissue
L.	78	Lung abscess	Pneumonec- tomy	Bronchopneu- monia	18	Similar findings to above
W. C.	66	Carcinoma	Pneumonec- tomy	Bronchopneu- monia	30	Similar findings to above
F. M.	48	Carcinoma	Pneumonec- tomy	Coronary occlu- sion	39	See Fig. 20
D.	44	Carcinoma	Pneumonec- tomy	Metastatic ear- cinoma	5 mo.	See Figs. 19 and 21
N. T.	54	Carcinoma	Pneumonec- tomy	Metastatic ear- cinoma	10 mo.	Bronchial fistula due to undetected can- cer in bronchial stump
D. T.	65	Pulmonary tu- berculosis	Pneumonec- tomy	Coronary occlu- sion	2 yr. 9 mo.	Fat graft viable ad- herent to stump by adult connective tissue

grossly normal. In the other nine cases, the pericardial fat graft was viable and tightly adherent to the bronchial stump in periods of from one day up to two years and nine months.

The gross appearance of a typical fat graft is shown on photograph at the post-mortem examination of a patient who died of metastatic carcinoma five months after pneumonectomy (Fig. 19). The microscopic findings are similar to those reported on the animal experiments. The same difficulty was encountered in cutting the microscopic sections, due to the fact that the tantalum wire sutures injured the microscopic section knives and these sutures had to be removed from the blocks before cutting. This resulted in considerable fraying of the material. However, leukocytic infiltration of the graft occurred early. Gradual replacement with fibroblasts and adult connective tissue of the portions of the bronchial wall and the adjacent graft tissue were noted. Outside the zone of fibrous adherence of the graft to the bronchial wall, the fatty tissue appeared healthy and a number of small blood vessels could be seen. The bronchial stump was completely lined with columnar epithelium in most instances, although occasionally a more transitional or cuboidal type of epithelium was seen. Some of the fat cells were phagocytosed and replaced with connective tissue, as observed in the experimental animals. However, the solid fibrous union of the graft in the wall of the major bronchus was clearly demonstrated (Figs. 20 and 21).

edges of the bronchus with simple sutures, they rely on a layer of pleura to reinforce the bronchial closure. Free grafts of lung tissue have been advocated for the bronchial stump by Churchill,²² Peribronchial tissues have been drawn over the stump by Adams²³ and others, and Gelfoam has been advocated to reinforce the bronchial closure by Hanlon.²⁴

Practically every type of suture material has been used for the bronchus. This includes silk (Rienhoff²⁵ and others), catgut (Shenstone and Janes²¹), a running stitch of silk (Holst²⁶), cotton (Oschner²⁷), stainless steel (Jones²⁷), and tantalum wire (the authors).

In reviewing the results of pulmonary resection with the current techniques that have been mentioned for bronchial closure, a tremendous variation in the reported incidence of bronchial fistula is found. This variation ranges from 1 per cent²² to as high as 40 per cent.²⁵ (This latter figure does include some tourniquet type of resection.) Perhaps, the average of reported incidence of bronchial fistula could be estimated as being from 8 to 15 per cent, although improvements in results are being reported. However, in reviewing these diverse reports in the literature, we find that there are many variables entailed in the compilation of such an average. These variables include the age of the patient, the amount and friability and infection of the bronchial wall, the use of antibiotics, the proper preparation of the patient, adequate postoperative care, etc. No two reports contain the same consideration of these variables. Thus, it becomes apparent that the assembling and mathematical calculation of such statistics from these widely divergent series (which was originally the plan) is not of true statistical value. We can conclude that while some people are not having much trouble with bronchial closure, in many reported series, bronchial closure is still an important clinical problem. We believe also that in nonreported series of cases, it is probably even more a clinical problem.

From this study, it can be concluded that sound surgical principles must be followed in closure of the bronchus to prevent the formation of a broncho-pleural fistula following total pneumonectomy or lobectomy. In all of our cases, there was careful preparation of the patient to decrease bronchopulmonary infection and bronchial secretions. The importance of the proper antibiotic in addition to drainage procedures to minimize the bronchial infection cannot be stressed too much. During the operation constant aspiration of blood and secretions from the bronchial tree must be carried out even if the operation has to be sometimes considerably prolonged by this attention to the bronchial toilet. The better the preparation of the patient before surgery, the less trouble is encountered during and after surgery. The actual care of the bronchial stump must include the preservation of the blood supply up to the end of the stump, the avoidance of clamps and other trauma to the proximal end of the bronchus to be sutured, and the cutting of the bronchus in such a way as to avoid tension on the suture line. We feel that this is best effected by our method of making a small elliptical flap of the membranous portion of the bronchus, thus tension on the suture line is completely prevented. The actual suture of the bronchial stump is performed with simple

Fig. 20.

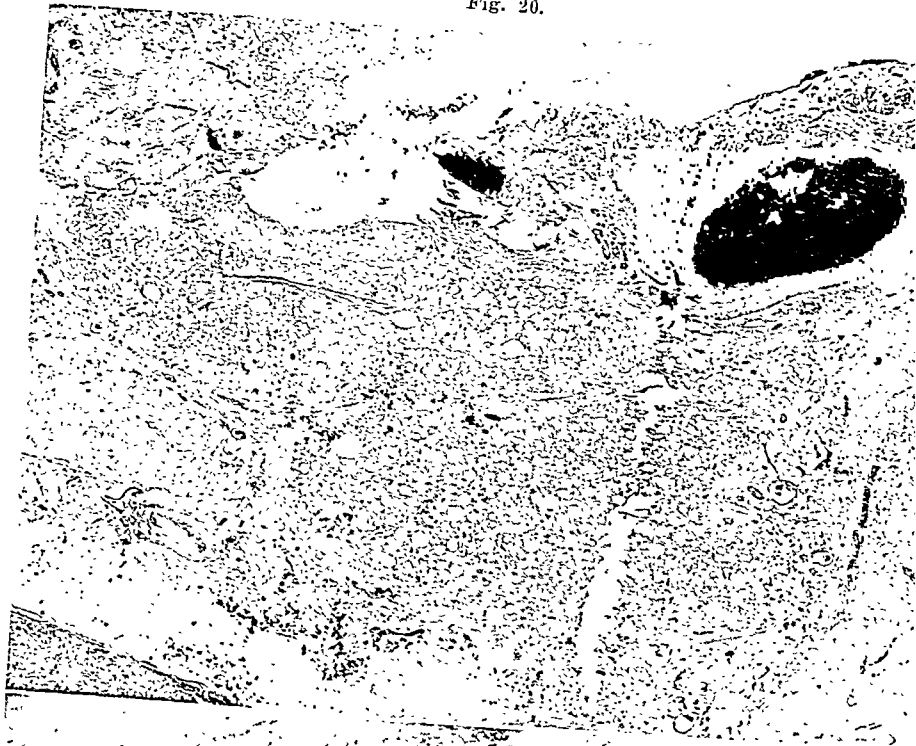


Fig. 21.

Fig. 20 (Case M).—Low-power
tient who had a pneumonectomy for
Section has been torn in removing
united to bronchial wall by adult fibrous tissue. Note the blood vessel in lower left-hand
corner.

Fig. 21 (Case D).—Low-power microscopic section of bronchial stump of Fig. 20 five
months after pneumonectomy for bronchiogenic carcinoma. Fat graft seen in upper left corner
portion of section. Note recurrent carcinoma in lower left
corner.

boidal or pavement epithelium. Portions of the graft not touching the bronchus show some fibrosis, but in general resemble pericardial fat tissue seen elsewhere in the body.

4. The bronchial reinforcement with the pericardial fat graft has entirely eliminated earlier bronchial fistulas during the first three weeks' time after operation in a series of 221 total pneumonectomies and lobectomies. Late bronchial fistulas occurred in 2.7 per cent of the cases. In an earlier series of 102 pulmonary resections in which the graft was not used, early bronchial fistulas were a real problem and made up four-fifths of the total number of fistulas. A total of 7.9 per cent of the patients developed bronchial fistulas in this nonfat graft series and three of the patients died as a result of the fistulas.

5. The employment of this technique of bronchial closure and pedicled viable pericardial fat graft reinforcement, as reported, appears to be a valuable addition to the surgery of pneumonectomy and pulmonary lobectomy.

6. A brief historical résumé of pulmonary resection and bronchial closure has been included.

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interrupted sutures that pass through the entire wall of the bronchus to firmly unite the mucosa. In most instances, the membranous flap is actually drawn over the rigid cartilaginous wall. The suture material is not as important as the manner in which it is used, since successful closures have been reported with fine absorbable and nonabsorbable sutures. However, since we've had such excellent results with tantalum wire, we will continue to use it. There seems to be general agreement that the bronchial stump should be covered by additional tissue. In our carefully controlled series of unselected cases, the viable pedicled pericardial fat graft proved greatly superior to all other methods. We must remember, however, that the use of antibiotics and pre- and postoperative care are extremely important. All of our cases have had liberal doses of vitamin C to promote healing following surgery.

The question remains, Should the pericardial fat graft be used routinely in all cases where the divided bronchial wall appears normal? Our experience with lobectomy in our two series does not show a great deal of improvement with the protecting influence of the graft, although the occurrence of late bronchial fistula was reduced from 2 per cent to 0.5 per cent. In pneumonectomy, however, there is no question that the graft should be used routinely for we had 5 per cent bronchial fistula before the first week, and three deaths directly due to these bronchopleural fistulas. With the grafts, however, there were no early bronchial fistulas before the fourth week and no deaths at any time from the opening of the bronchus. Thus, it is certain that the bronchial grafts are definitely indicated routinely in pneumonectomy and in all lobectomies where there is any question about the status of the bronchial wall or the effectiveness of the bronchial closure. Since it is extremely difficult to tell whether or not a bronchus is normal by gross inspection, this will leave only a few cases in which it is safe to omit the graft. Even though the occurrence of fistulas in lobectomy is rare, for any one patient that occurrence is 100 per cent. Because of this we shall continue to use this form of graft routinely in all cases.

SUMMARY

1. Our technique of bronchial closure, employing a curved posterior membranous flap which is sewn to the rigid cartilaginous wall of the main bronchus and the use of a viable, pedicled, pericardial fat graft reinforcement, has been presented.

2. The grafts of this "thoracic omentum" have been found to be intact, viable, and effectively reinforcing the bronchial stump one year after operation in experimental animals and up to 2 years and nine months in human beings on post-mortem examination.

3. Microscopic examination of the graft in experimental animals and human beings shows that first a leukocytic infiltration of the portion of the graft next to the stump, then the fibroblastic infiltration and replacement of portions of the graft next to the bronchus with an adult type of connective tissue. The bronchial stump is lined with columnar and occasionally low cu-

CIRCULATION THROUGH AN ATELECTATIC LUNG IN MAN

VIKING OLOV BJÖRK, M.D.

STOCKHOLM, SWEDEN

IN AN experimental series performed using dogs, E. F. Salén and I studied the blood flow through an atelectatic lung with the aid of angiocardiology.

In an acute atelectasis of one lung the pulmonary arteries to that lung did not become smaller. The capillary bed remained open; this was indicated by the contrast medium's simultaneous filling of the pulmonary arteries and veins on both sides. The contrast filling of the periphery of the atelectatic lung was as little pronounced as on the other side. A pronounced decrease of the arterial oxygen saturation indicated a big shunt, that is, a considerable amount of blood passing the atelectatic lung.

In permanent atelectasis there was a continuous decrease of blood flow during the first month, until practically no blood was passing through the nonventilated part of the lungs. At the same time there was no decrease in the size of the main branches of the pulmonary artery.

In long-standing atelectasis the pulmonary artery decreased in size. After one month the diameter of the main pulmonary arteries, measured on the angiocardiology, was 15 mm. on both sides. After eight months of atelectasis of the right lung the diameter of its main pulmonary artery measured 9 mm. as compared with a diameter of 15 mm. for the left pulmonary artery. The contrast medium did not disappear from the artery in the atelectatic lung in the same time as on the healthy side nor were the pulmonary veins filled with contrast medium in the atelectatic part at the same time as on the healthy side. The blood was therefore considered to fill the arteries of the atelectatic lung but either to pass not at all or to pass extremely slowly through the capillary bed.

Attempts to study the circulation through atelectatic lungs in man with angiocardiology have, however, not been successful so far. The density of the atelectatic lung with underlying disease in the clinical cases has made visualization of the finer branches of the pulmonary artery and veins impossible with contrast medium. In one patient who had more than one year's total atelectasis of the left lung only the main pulmonary artery on the left side was demonstrated. When all contrast had disappeared from the right pulmonary artery, the left branch to the atelectatic lung was still well demonstrated with high concentration of the contrast medium. This finding suggests a negligible circulation through the atelectatic lung. As no further information was obtained by angiography the following method was employed.

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DISCUSSION

DR. RICHARD H. MEADE, Grand Rapids.—I think the authors have made a worthwhile contribution. I should like to ask if they have used this method in the treatment of bronchial fistulas.

DR. BREWER (Closing).—I can answer Dr. Meade's question very simply by saying that we have not used this method in the treatment of bronchial fistulas. All the bronchial fistulas in this series came on after three weeks' time and were treated by simple drainage. In all instances except one, where the patient had carcinoma in the bronchial stump, the bronchial fistula closed spontaneously following simple drainage.

I do believe that the pedicled pericardial fat graft can be used as an aid to close bronchial fistulas provided that (1) care is used to preserve the blood supply to the graft, and (2) adequate excision of the infected bronchial tissue is made. We have shown in experimental animals, in the incompletely closed bronchus, that fibroblasts proliferate in three days from the clean bronchial stump and by eight days the stump is epithelized when protected by the graft.

It seems reasonable, therefore, from this and from the examination of the firm fixation of the grafts seen at autopsy, that this method would be useful in closing bronchial fistulas.

This subject has been of consuming interest to our group. I gather from the lack of people springing to their feet to proclaim that they never heard of a bronchial fistula, that it is still a problem to most of us.

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DISCUSSION

DR. RICHARD H. MEADE, Grand Rapids.—I think the authors have made a worthwhile contribution. I should like to ask if they have used this method in the treatment of bronchial fistulas.

DR. BREWER (Closing).—I can answer Dr. Meade's question very simply by saying that we have not used this method in the treatment of bronchial fistulas. All the bronchial fistulas in this series came on after three weeks' time and were treated by simple drainage. In all instances except one, where the patient had carcinoma in the bronchial stump, the bronchial fistula closed spontaneously following simple drainage.

I do believe that the pedicled pericardial fat graft can be used as an aid to close bronchial fistulas provided that (1) care is used to preserve the blood supply to the graft, and (2) adequate excision of the infected bronchial tissue is made. We have shown in experimental animals, in the incompletely closed bronchus, that fibroblasts proliferate in three days from the clean bronchial stump and by eight days the stump is epithelized when protected by the graft.

It seems reasonable, therefore, from this and from the examination of the firm fixation of the grafts seen at autopsy, that this method would be useful in closing bronchial fistulas.

This subject has been of consuming interest to our group. I gather from the lack of people springing to their feet to proclaim that they never heard of a bronchial fistula, that it is still a problem to most of us.

been taken for oxygen determination according to the method of Van Slyke and Neill. Double determinations of oxygen content as well as of oxygen capacity are made on each sample.

The blood samples are taken in the following order: 1. The first sample is from aorta (A_1). This sample contains mixed blood from the aerated and from the atelectatic lung (Fig. 2). 2. The second sample is from one pulmonary vein from the atelectatic lung (V). In case of lobar atelectasis samples are taken from both pulmonary veins. Before this sample is taken the vein is ligated or clamped as close to the pericardium as possible.

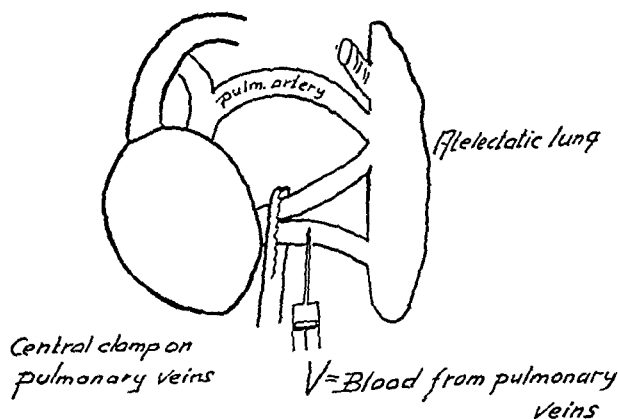


Fig. 3.— V = blood from the pulmonary veins draining the atelectatic lung.

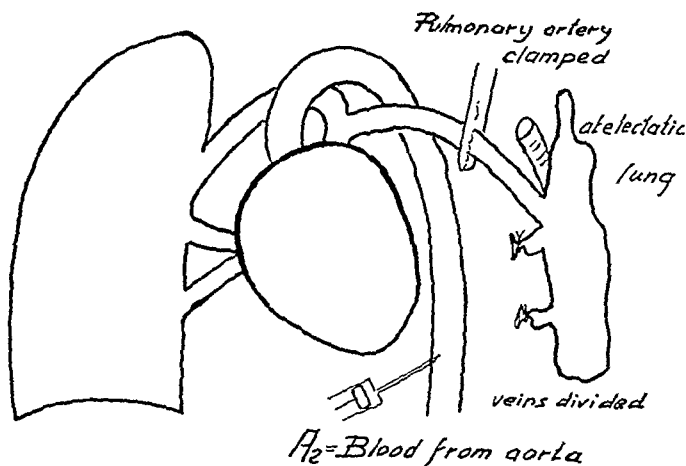


Fig. 4.— A_2 = blood from the aorta after the division or occlusion of the pulmonary veins from the atelectatic lung is identical to the blood from the pulmonary veins of the aerated lung.

Then the needle is introduced peripheral to the clamp. Thus a back-flow from the left auricle is eliminated. Immediately after the second sample is taken an arterial clamp is placed on the pulmonary artery to prevent the lobe or lung from being overloaded by blood (Fig. 3). 3. The third sample is from the aorta (A_2). This sample is taken after both the superior and inferior pulmonary veins are clamped or ligated. Even the pulmonary artery must be clamped in cases of acute atelectasis. The blood sample then represents the blood from the pulmonary veins on the opposite side, which without admix-

METHOD

For the determination of the blood flow to each lung separately Weiss, in 1926, used a formula necessitating the use of blood samples from a pulmonary vein both from the aerated and the collapsed lung as well as from the left ventricle. In an excellent experimental study Keeley and Gibson (1942) used this formula on dogs after having performed bilateral thoracotomies.

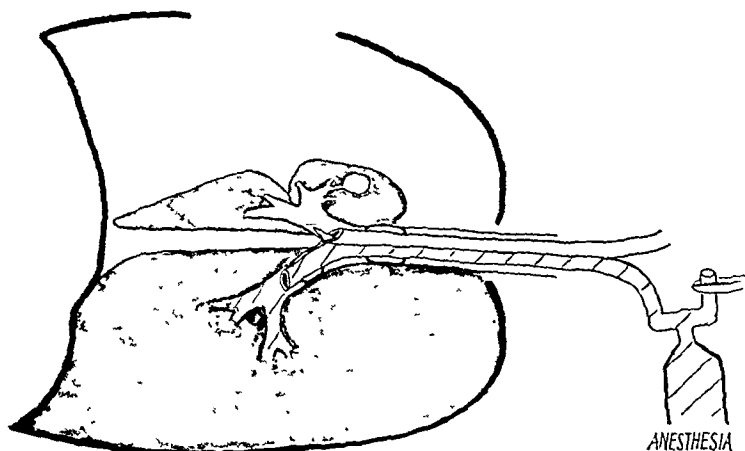


Fig. 1.—Acute atelectasis is obtained by the use of a double lumen catheter (Carlens). When the tube to the operated side is opened the lung will be completely atelectatic.

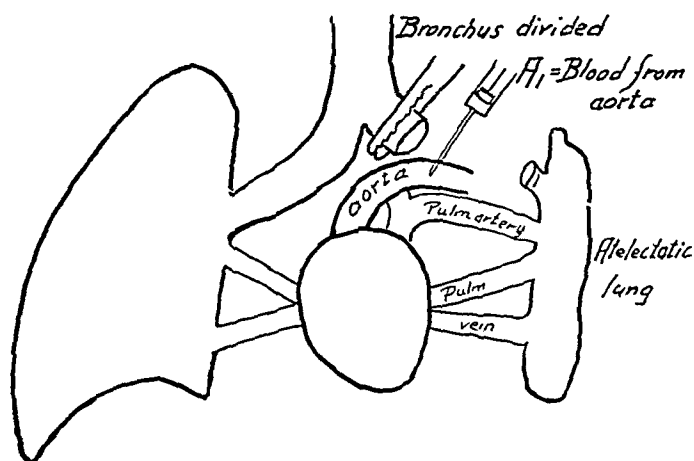


Fig. 2.— A_1 = blood from the aorta containing mixed blood from the aerated and from the atelectatic lung.

In order to make the determination of blood flow through an atelectatic lung possible on man I have worked out the following method: Acute atelectasis is obtained during intrathoracic surgery by the use of a double lumen catheter (Carlens) for endobronchial anesthesia. The tube, corresponding to the operated side, is opened to atmospheric pressure when the lung is completely atelectatic (Fig. 1). Anesthesia is then given only to the opposite lung. Nitrous oxide, oxygen, and curare has been the anesthesia of choice. After isolation of the pulmonary artery and veins and the bronchus, blood samples have

AGE	SEX	DIAGNOSIS	DURATION OF ATELECTASIS	A ₁				A ₂				V				P				THROUGH DISTENDED LUNG IN % OF TOTAL FLOW	BLOOD FLOW THROUGH OPEN VEINS IN ML./MIN.	COMMENTS
				O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂			
30	F	TBC stenosis left main bronchus	2 yr.	100.0	51.4	100.0	52.8	68.0	49.1	—	—	—	—	—	—	—	—	—	—	0	420	Probably accumulation of blood as veins were clamped 15 minutes before they were opened
46	F	Total atelectasis, left lung with fibrosis	9 mo.	100.0	38.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	
48	F	TBC stenosis of left upper and lower lobe bronchi, 7 ribs thoracoplasty 2 years ago	2 mo.	87.3	56.7	88.2	53.8	60.8	56.8	—	—	—	—	—	—	—	—	—	—	3.3	90	Bronchial arteries not divided
29	F	Destroyed lung. Bronchiectasis	23 yr.	94.6	52.1	93.2	50.4	51.0	54.9	59.0	54.4	—	—	—	—	—	—	—	—	0	—	
25	M	TBC with atelectasis under 6-rib thoracoplasty	6 yr.	67.0	48.7	65.0	48.0	52.0	48.2	48.2	50.0	—	—	—	—	—	—	—	—	0	—	Bronchospirometry showed 0% oxygen uptake on the left side
33	F	TBC stenosis left main bronchus and pneumothorax	8 yr.	90.4	49.3	100.0	48.2	77.3	—	86.2	50.8	—	—	—	—	—	—	—	—	2.7	—	
31	M	TBC stenosis left main bronchus	3 yr.	76.4	46.8	86.1	47.2	35.4	51.3	58.3	50.1	—	—	—	—	—	—	—	—	19.0	34	
44	F	TBC stenosis left main bronchus, 7-rib thoracoplasty	9 yr.	89.2	43.7	87.8	43.3	55.6	44.8	68.2	45.6	—	—	—	—	—	—	—	—	0	80	
27	F	TBC empyema left side and 7-rib thoracoplasty	2 yr.	96.4	46.7	100.0	47.3	57.6	52.0	65.7	50.8	—	—	—	—	—	—	—	—	8.5	50	Bronchospirometry showed 0% oxygen uptake on the left side
30	F	TBC stenosis left main bronchus	5 yr.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	28	
33	M	TBC stenosis left main bronchus and pneumothorax	3 yr.	100.0	48.4	85.0	42.5	66.4	43.2	81.8	44.4	—	—	—	—	—	—	—	—	0	84	
Mean Value:				91.0	47.6	89.5	48.3	58.3	50.1	66.7	49.4	—	—	—	—	—	—	—	—	0	98.3	

A₁ = blood from aorta before occlusion of the veins.A₂ = blood from the aorta after occlusion of the pulmonary veins.

V = blood from the pulmonary veins.

ing goes through the left auricle and ventricle and out in the aorta (Fig. 4). It is, however, necessary to wait a few minutes after ligation of both veins so that the mixed residual blood in the left ventricle is washed away. In our patient the third sample (A_2) was taken immediately after ligation of both upper and lower pulmonary veins, and the arterial oxygen content was 95.9 per cent in a case of one hour's atelectasis. Another sample, taken two minutes later from the same patient's aorta, showed an arterial oxygen content of 99.2 per cent.

Calculation.— x represents the percentage of total pulmonary blood flow through the aerated lung. y represents the percentage of total pulmonary blood flow through the atelectatic lung. $x + y = 100$ per cent of the pulmonary blood flow. $y = 100 - x$. Then the following equation is achieved:

$$\begin{aligned} A_2x + Vy &= A_1(x + y) \\ y &= 100 - x \\ A_2x + 100V - Vx &= 100A_1 \\ x(A_2 - V) &= 100(A_1 - V) \\ x &= \frac{100(A_1 - V)}{A_2 - V} \end{aligned}$$

In cases of chronic atelectasis the blood flow through the opened pulmonary veins with intact pulmonary artery and divided bronchial arteries was measured during operation (Fig. 5). These observed values of blood flow were compared to the values calculated from the above-mentioned formula. See Tables I and II.

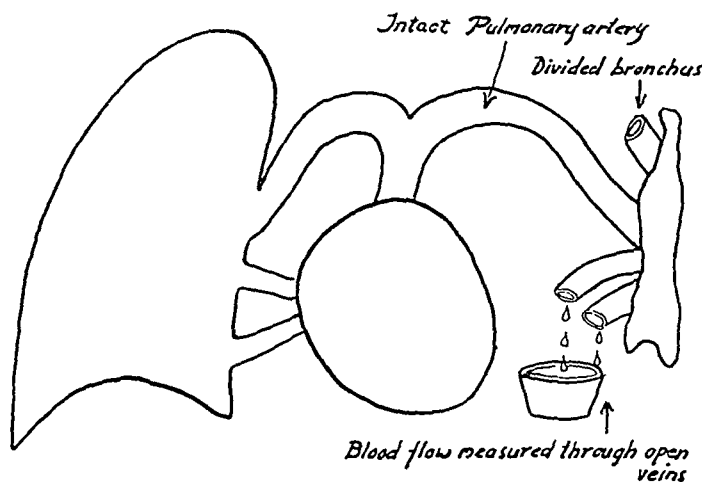


Fig. 5.—In cases of chronic atelectasis the blood flow was measured through the open veins when the pulmonary artery was intact and the bronchial arteries divided.

The Influence of the Bronchial Circulation.—It has been my intention to study the circulation through the pulmonary artery separately without the admixture of blood from the bronchial arteries. In bronchiectases and in many cases of pulmonary tuberculosis the bronchial circulation is considerable, but in tuberculosis with bronchial stenosis and total atelectasis only small bronchial arteries are usually found at the operation. In acute atelectasis the admixture of blood from the bronchial arteries would hardly influence the result, as the volume of flow through the pulmonary artery is so much greater. In chronic atelectasis, however, where the flow through the pulmonary artery is negligible, an admixture of blood from the bronchial artery must be excluded. Furthermore in atelectatic lungs with bronchiectatic changes there are much larger anastomoses between the bronchial and pulmonary arteries than in normal cases. Only sample A_1 and V would be influenced

by the bronchial circulation, which is drained into the pulmonary veins as well as through the intercostal, the azygos, and hemiazygos veins into the superior vena cava. When sample A_2 is taken, both pulmonary veins are clamped or ligated to exclude admixture from the bronchial circulation. To exclude bronchial circulation in chronic atelectasis where the lung is going to be removed, all bronchial arteries are tied and the bronchus is divided. In cases where an acute atelectasis is produced and only part of the lung or a mediastinal tumor is removed, the main bronchus is dissected and clamped together with the bronchial arteries with the noncrushing aorta clamp constructed by Crafoord. This technique is used to produce a bloodless field in the enucleation resections of benign intrapulmonary tumors. In patients with acute atelectasis an abnormal bronchial artery joining the lung peripheral to the clamped bronchus may be encountered, but this admixture will not significantly influence the values of flow through the pulmonary artery.

Criticism of the Method.—The limitation of this method lies in the oxygen saturation determination. Due to the form of the oxyhemoglobin dissociation curve, which is very flat at high tensions, small changes in the arterial-oxygen content may not be detected with the saturation determination. From a theoretical point of view arterial oxygen tension determinations are therefore preferred. Direct oxygen tension measurements, however, have not been performed during operations due to the admixture of nitrous oxide to the blood.

ACUTE ATELECTASIS OF ONE HOUR'S DURATION

Acute atelectasis of the right lung was produced in two cases during operation.

CASE 1.—A 59-year-old man had a segmental atelectasis of the posterior segment of the right upper lobe due to a squamous-cell bronchiogenic carcinoma.

CASE 2.—A 23-year-old woman had a tuberculous cavity in the apical segment of the right lower lobe. The determination was made after resection of the diseased segment.

The duration of the total atelectasis of the right lung was one hour in both instances. The values shown in Tables III and IV were obtained.

TABLE III. ACUTE ATELECTASIS FOR ONE HOUR OF THE RIGHT LUNG

	A_2			V			A_2			BLOOD FLOW	
	% O ₂	VOL % CO ₂	% O ₂	VOL % CO ₂	% O ₂	VOL % CO ₂	% O ₂	VOL % CO ₂	% O ₂	VOL % CO ₂	
Case 1	81.6	48.1	62.8	49.9	99.2	46.0	48.4	42.4	48.4	51.6	RIGHT LUNG
Case 2	81.0	42.4	70.0	40.7	99.5	36.0	42.4	42.4	42.4	57.6	LEFT LUNG

A_2 = blood sample from aorta.

V = blood sample from the right pulmonary veins.

A_2 = blood sample from aorta after division of the right pulmonary veins.

TABLE IV. BRONCHOSPIROMETRY IN CASE 2

	RIGHT LUNG	LEFT LUNG
Minute ventilation	46.5%	53.5%
Oxygen uptake	37.3%	62.2%

Conclusion.—In both cases the right lung had been atelectatic for one hour. In the first case, where the posterior segment of the right upper lobe was diseased, 48.4 per cent of the total blood flow through the lungs passed the atelectatic right lung. This may be considered to be about the normal proportion of blood flow through the lungs in spite of atelectasis for one hour of the right lung.

TABLE II. CASES WITH TOTAL ATELECTASIS OF LEFT UPPER LOBE, RELATIVE MAIN BRONCHUS STENOSIS, AND HYPERINFLATION OF EMPHYSEMATOUS LOWER LOBE

AGE	SEX	DIAGNOSIS	DURATION OF ATELECTASIS IN YEARS	A ₁		A ₂		V _{sup}		V _{inf}		P		CALCULATED FLOW THROUGH DISEASED UPPER LOBE IN % TOTAL FLOW	BLOOD FLOW THROUGH OPEN	
				O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂	SUP. PULM. VEIN ML./MIN.	INT. PULM. VEIN ML./MIN.			
32	M	TBC stenosis left upper lobe, Relative main bronchus stenosis	3	94.4	50.3	96.8	50.7	67.9	53.6	97.1	47.6	69.4	54.4	7.7	33.0	171
49	M	TBC stenosis left main bronchus hyperinflated over lobe	8	95.9	49.3	97.3	50.6	90.7	50.3	67.7	52.0	80.5	51.1	4.7	41.0	65
38	F	TBC stenosis left upper lobe, Hyperinflation lower lobe	4	100.0	50.9	93.6	48.0	69.2	53.3	79.1	54.8	79.5	53.4	0	32.0	156
48	F	TBC stenosis left upper lobe, Relative stenosis left lower lobe with hyperinflation 7-rib thoracoplasty	3	100.0	45.5	100.0	45.0	84.6	43.7	83.9	42.9	82.9	45.9	0	43.5	360
Mean Values				97.6	49.0	96.9	48.6	78.1	50.2	82.0	49.3	78.1	51.2	0	37.4	188

Blood from: A₁ = aorta before occlusion of veins.
A₂ = aorta after occlusion of veins.
V_{sup} = superior pulmonary vein.
V_{inf} = inferior pulmonary vein.
P = the pulmonary artery.

by the bronchial circulation, which is drained into the pulmonary veins as well as through the intercostal, the azygos, and hemiazygos veins into the superior vena cava. When sample A_2 is taken, both pulmonary veins are clamped or ligated to exclude admixture from the bronchial circulation. To exclude bronchial circulation in chronic atelectasis where the lung is going to be removed, all bronchial arteries are tied and the bronchus is divided. In cases where an acute atelectasis is produced and only part of the lung or a mediastinal tumor is removed, the main bronchus is dissected and clamped together with the bronchial arteries with the noncrushing aorta clamp constructed by Crafoord. This technique is used to produce a bloodless field in the enucleation resections of benign intrapulmonary tumors. In patients with acute atelectasis an abnormal bronchial artery joining the lung peripheral to the clamped bronchus may be encountered, but this admixture will not significantly influence the values of flow through the pulmonary artery.

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	A_1		V		A_2		BLOOD FLOW	
	% O ₂	VOL. % CO ₂	% O ₂	VOL. % CO ₂	% O ₂	VOL. % CO ₂	RIGHT LUNG	LEFT LUNG
Case 1	81.6	48.1	62.8	49.9	99.2	46.0	48.4%	51.6%
Case 2	87.0	42.4	70.0	40.7	99.5	36.0	42.4%	57.6%

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V = blood sample from the right pulmonary veins.

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				O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂		SUP. PULM. VEIN ML./MIN.	INF. PULM. VEIN ML./MIN.
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38	F	TBC stenosis left upper lobe, Hyperinflation lower lobe	4	100.0	50.9	93.6	48.0	69.2	53.3	79.1	54.8	79.5	53.4	0	32.0	156
48	F	TBC stenosis left upper lobe, Relative stenosis left lower lobe with hyperinflation 7-rib thoracoplasty	3	100.0	45.5	100.0	45.0	84.6	43.7	83.9	42.9	82.9	45.9	0	43.5	360
Mean Values				97.6 49.0		96.9 48.6 78.1		50.2 82.0		49.3 78.1		51.2		0	37.4	188

Blood from: A₁ = aorta before occlusion of veins.
A₂ = aorta after occlusion of veins.
V_ssup = superior vena cava.
V_{inf} = inferior vena cava.

Blood from: A₁ = aorta before occlusion of veins.

A₂ = aorta after occlusion of veins.

V_{sup.} = superior pulmonary vein.

V_{inf.} = inferior pulmonary vein.

P = the pulmonary artery.

The Main Pulmonary Artery.—The size of the main pulmonary artery showed great variations. In four cases the pulmonary artery had a normal size in spite of total atelectasis which had been present for one to three years. In three cases the pulmonary artery had a nearly normal size 70 mm. in spite of the fact that the lung was completely collapsed for nine years.

In two cases the pulmonary artery had considerably diminished in size. The circumference was only 35 to 40 mm., approximately half the size of the normal artery. The duration of the atelectasis was twenty-three and eight years, respectively. In the remaining six cases a varying decrease of the size of the pulmonary artery was found.

Conclusion.—In cases of chronic atelectasis the main pulmonary artery may for many years retain its normal size. The pulmonary artery is then only functioning as a blind sac with a negligible amount of blood flow (probably in a reverse direction) through the destroyed lung. After several years the pulmonary artery to the destroyed lung slowly diminishes in size. The most pronounced decrease observed was about 50 per cent.

The Branches of the Pulmonary Artery.—The peripheral branches of the pulmonary artery to a diseased area are often diminished in size. We have encountered complete thromboses of the anterior trunk to the right upper lobe, the lingular artery, and the artery to the apical segment of the left lower lobe in cases of tuberculosis.

The Pulmonary Veins.—The pulmonary veins of the lungs having long-standing atelectasis are nearly always considerably diminished in size.

The Bronchial Arteries.—In cases of chronic atelectasis due to tuberculosis great variation is found in the bronchial arteries. They are often very small, but considerably enlarged bronchial arteries may occasionally be found. In tuberculosis the bronchial arteries have never been found as large as in cases of bronchiectasis. Eleven cases of long-standing total atelectasis were investigated. The results can be seen in Table I.

CONCLUSIONS

In cases with total atelectasis or a destroyed lung the following observations were made:

1. The oxygen saturation in the aorta was on an average the same before (91.0 per cent) and after (89.5 per cent) the occlusion of the pulmonary veins from the diseased lung.
2. The amount of blood flowing through the diseased lung was 0 per cent, calculated from the mean values.
3. The amount of blood flowing through the diseased lung observed during operation was on an average 98 ml. per minute.
4. The mean value of the oxygen saturation in the pulmonary artery (66.7 per cent oxygen) was significantly higher than in the pulmonary veins (58.3 per cent oxygen). This may be due to an admixture of blood from the bronchial arteries draining blood into the pulmonary artery in a reverse direction.

In Case 2 the blood samples were taken after the apical segment of the right lower lobe was removed. This segment is usually larger than the posterior segment of the upper lobe. The finding that 42.4 per cent of the total blood flow was passing the right lung after atelectasis for one hour is considered to correspond to a normal proportion. When the patient underwent a bronchospirrometry one year after the operation the oxygen uptake on the right side was found to be 37.8 per cent (the minute ventilation on the right side was 46.5 per cent). The oxygen uptake of each lung is considered to be a good expression for the blood flow through each lung.

Therefore the conclusion that can be drawn from these two cases is that after one hour of total atelectasis a normal amount of blood is still passing the atelectatic lung.

ATELECTASIS FOR ONE AND ONE-HALF MONTHS

A 22-year-old girl had a left lower lobe bronchial stenosis of tuberculous origin and a long-standing lower lobe atelectasis. The upper lobe was well aerated under the artificial pneumothorax. After a first-stage upper 5-rib thoracoplasty the upper lobe, too, was atelectatic for one and one-half months. Then a left lower lobectomy and decortication of the upper lobe was performed. At the end of the operation the blood flow through the remaining left upper lobe that had been atelectatic for one and one-half months was found to be negligible. The following values were obtained:

SAMPLES	O ₂ SATURATION
A ₁ (aorta before occlusion of V)	= 98.5% O ₂
V (left upper pulmonary vein)	= 60.0% O ₂
A ₂ (aorta after occlusion of V)	= 91.0% O ₂

The upper lobe had been atelectatic for one and one-half months. Now it was ventilating. However, the calculated flow through this lobe equaled zero. One year after the resection this patient underwent a bronchospirrometry which showed 15.7 per cent oxygen uptake and 28 per cent minute ventilation for the remaining left upper lobe. Thus the same function was achieved that had existed before the atelectasis when the oxygen uptake of left upper lobe was 14.3 per cent and the minute ventilation 27 per cent of the total.

Conclusion.—After atelectasis for one and one-half months no blood passed this left upper lobe in spite of decortication and positive pressure ventilation. Bronchospirrometry one year later showed 15.7 per cent oxygen uptake and 28 per cent minute ventilation for this remaining left upper lobe. Exactly the same function had then returned as was found before the atelectasis (oxygen uptake 14.3 per cent and minute ventilation 27 per cent).

CHRONIC ATELECTASIS

The same decrease of blood flow was found in a destroyed lung due to bronchiectasis as was found in cases of tuberculosis with or without bronchial stenosis.

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5. In cases of total atelectasis only a negligible amount of blood passes the pulmonary artery. Thus the pulmonary artery is probably acting more or less as a blind sac with a slow reverse flow of blood from the bronchial arteries. In four cases with total atelectasis of the left upper lobe and a relative stenosis of the main bronchus of the lower lobe with hyperinflation of an emphysematous lower lobe the observations demonstrated in Table II were made.

In cases of total atelectasis of the left upper lobe and hyperinflation of the emphysematous lower lobe the following findings were made:

1. The oxygen saturation, in the aorta, was on an average the same before (97.6 per cent oxygen) as after (96.9 per cent oxygen) occlusion of the pulmonary veins from the diseased lung.

2. The amount of blood flowing through the diseased lung was calculated to 0 per cent on the mean values.

3. The amount of blood flowing through the atelectatic lobe (37.4 ml. per minute) was considerably smaller than the amount passing the hyperinflated lobe (188 ml. per minute).

4. The mean oxygen saturation in the pulmonary artery (78.1 per cent) was the same as in the superior pulmonary vein (78.1 per cent) but slightly higher in the inferior pulmonary vein (82 per cent).

SUMMARY

A method is presented for the determination of the relative blood flow through each lung during intrathoracic operations on man.

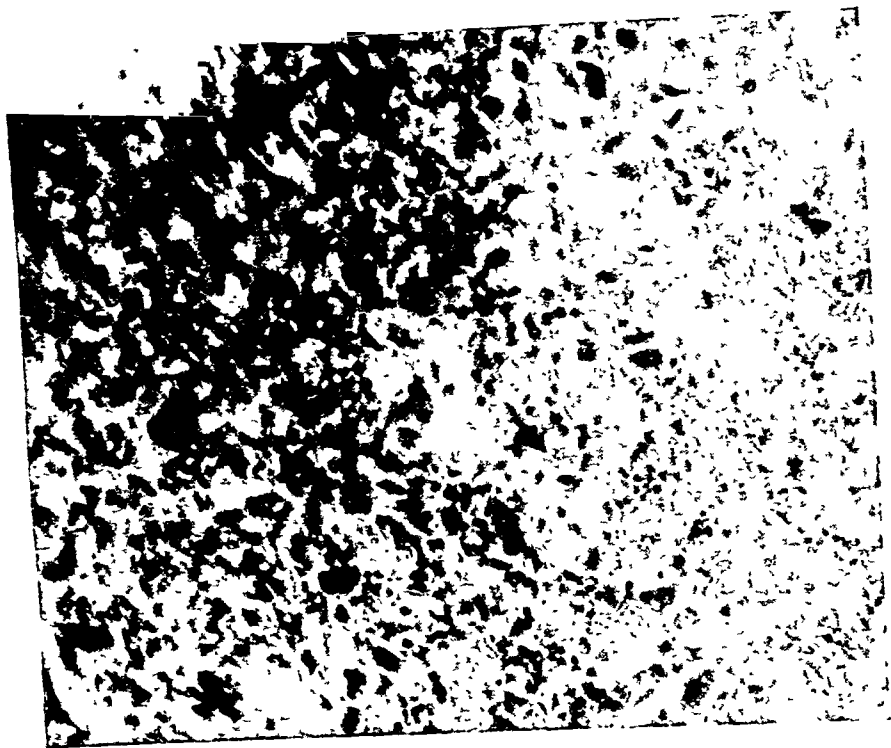
The values obtained correspond well to the direct measurement of blood flow through the opened pulmonary veins when the pulmonary artery is intact in cases of chronic atelectasis or destroyed lungs.

Acute atelectasis for one hour does not significantly decrease the blood flow through the atelectatic lung in man. After atelectasis for one and one-half months practically no blood was passing through the atelectatic lung. One year later the oxygen uptake on that lobe was 15.7 per cent.

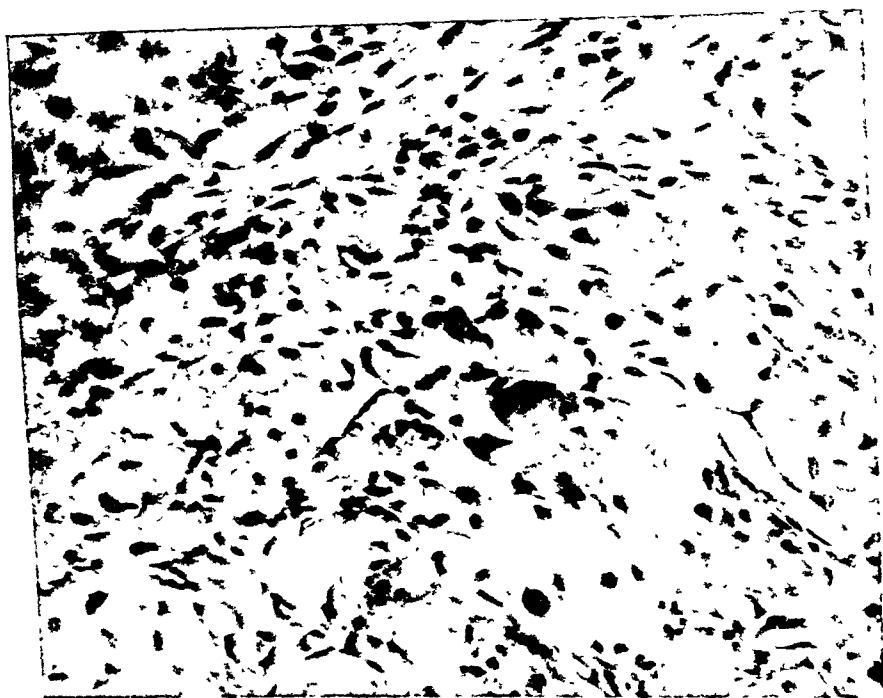
In cases of chronic atelectasis or destroyed lungs a negligible amount of blood passes through the diseased lungs. A higher oxygen saturation in the pulmonary artery than in the pulmonary veins suggests a reverse blood flow in the pulmonary artery with an admixture of blood from the bronchial arteries. In these chronic cases the amount of unsaturated blood leaving the pulmonary veins is too small to cause a decrease in the oxygen saturation of the arterial blood.

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A



B.

Fig. 1.—Photomicrographs of the original osteochondrogenic sarcoma of the tibia. A, A highly anaplastic area with many prominent nuclei and nucleoli. B, Cartilaginous elements with scattered areas of telangiectasis predominate in this section.

RESECTION OF MULTIPLE PULMONARY METASTASES FOURTEEN YEARS AFTER AMPUTATION FOR OSTEOCHONDROGENIC SARCOMA OF TIBIA

APPARENT FREEDOM FROM RECURRENCE TWO YEARS LATER

EDGAR P. MANNIX, JR., M.D.

BROOKLYN, N. Y.

ALTHOUGH there have been reported only a few patients with metastatic pulmonary neoplasms of osseous origin who have been treated by pulmonary resection, it is noteworthy that some excellent results have been obtained in this group. As early as 1883, Krönlein¹ removed a metastatic sarcoma in the left lower lobe; the patient lived for six years after the operation, dying of a recurrence of the primary neoplasm of the rib but without evidence of further pulmonary metastasis. One of Van Hazel's² patients was alive nine years after a left upper lobectomy for a metastatic osteogenic sarcoma. An even more striking case was that described by Edwards³ whose patient was alive eighteen years following pulmonary resection for a metastatic sarcoma of the fibula. The only reported case of pulmonary resection for multiple metastatic neoplasms of osseous origin of which we have knowledge is that described by Weinlechner.⁴ This patient died in the early postoperative period.

In the case described here, a total of six metastatic neoplasms was discovered in the left lung during exploratory thoracotomy. Prior to operation only one tumor was seen roentgenographically. All the palpable lesions were resected, and the patient, previously suffering from chest pain and hemoptysis, has been symptom free and without evidence of recurrence for twenty-four months following operation.

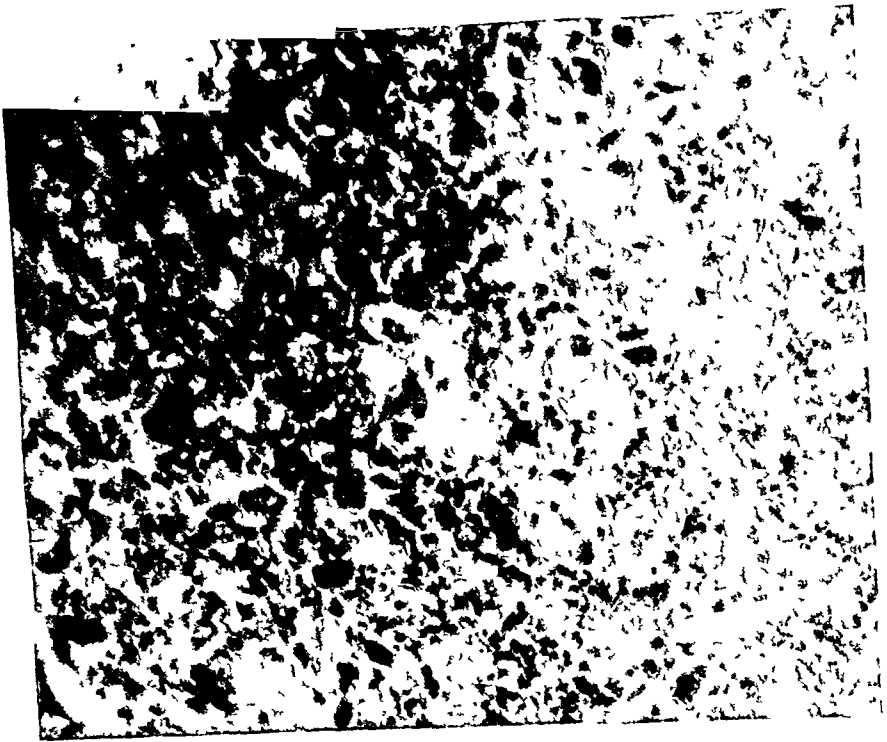
CASE REPORT

B. II., a 39-year-old white woman, was admitted to the University of Michigan Hospital (Reg. No. 666306) on Oct. 26, 1950. Fourteen years previously a left midthigh amputation had been performed for an osteochondrogenic sarcoma of the tibia (Fig. 1); chest roentgenograms showed no abnormality. In 1949, she developed pain in the left chest, night sweats, productive cough, and hemoptysis. At that time there was found in the roentgenogram of the chest a solitary opacity which was considered to be a tuberculoma. In view of a persistence of symptoms and slight enlargement of the lesion during the succeeding year, exploratory thoracotomy was advised.

At the time of admission the only abnormal sign was an unexplained tenderness over the amputation stump and along the left side of the chest. The bronchoscopic findings, laboratory data, and roentgenogram of the femoral stump were negative.

At operation on Nov. 3, 1950, six metastases were found in the left lung (Fig. 2). The largest of these, a firm ovoid mass 20 mm. in diameter, was the only lesion seen in the roentgenogram before operation and was one of five lesions located in the basilar segments of the left lower lobe. These tumors were removed by basilar segmentectomy. The sixth and smallest nodule was found on the anterior surface of the lingula and was resected locally.

From the Department of Surgery, University of Michigan, Ann Arbor, Mich.
Received for publication Feb. 23, 1953.



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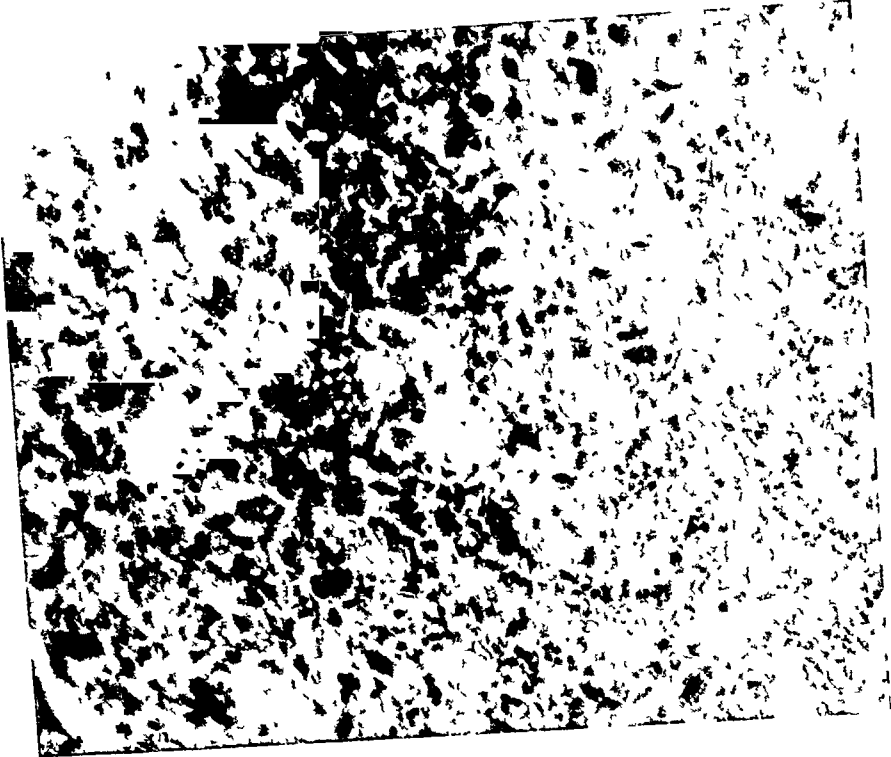
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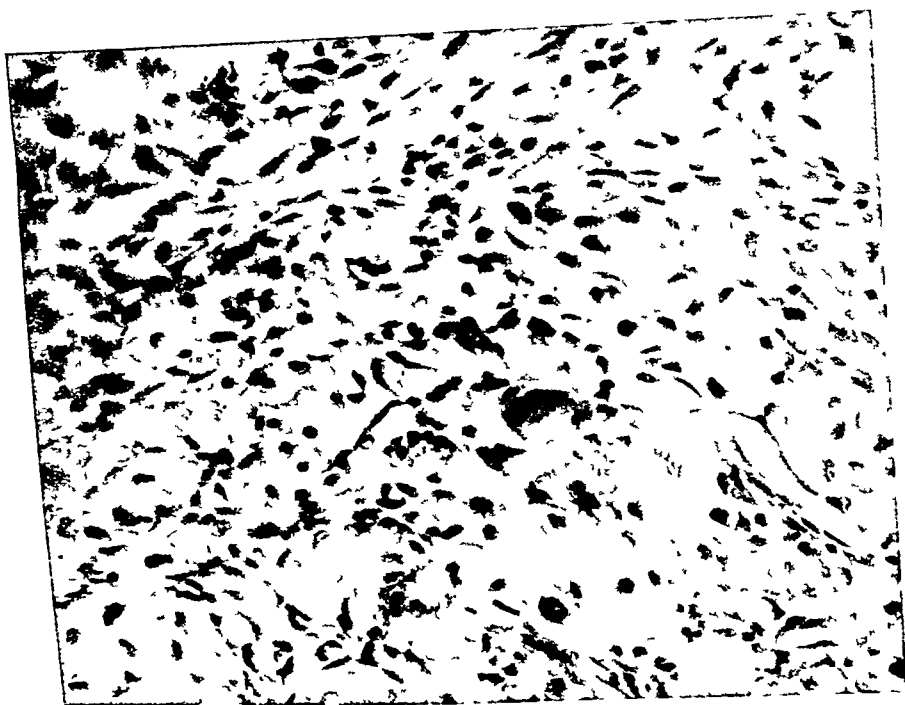
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The procedure was well tolerated and the postoperative course was uneventful. It is now twenty-four months since the operation. The patient has no symptoms, and lateral and posteroanterior roentgenograms of the chest are normal.

Histologically the lesions were described as cellular osteochondromata, metastatic to the lung.

DISCUSSION

Pathology.—The original neoplasm was a vascular osteochondrogenic sarcoma (Fig. 1, *A* and *B*). Geschickter⁵ states that the five-year survival rate in primary chondrosarcoma is 15 per cent. Inasmuch as there is at present no evidence of the existence of neoplasm in the amputation stump or elsewhere in the body, it seems probable that the pulmonary neoplasms were present prior to the amputation of the thigh. It may be that the local tissue resistance of the lung to the growth of neoplasms, as recently mentioned by Sommer,⁶ was a factor in their occasional suppression for so long a time. Metastatic pulmonary neoplasms are a threat to the patient not only because of their local effect in the lung, but also because they may act as sources of systemic embolization.

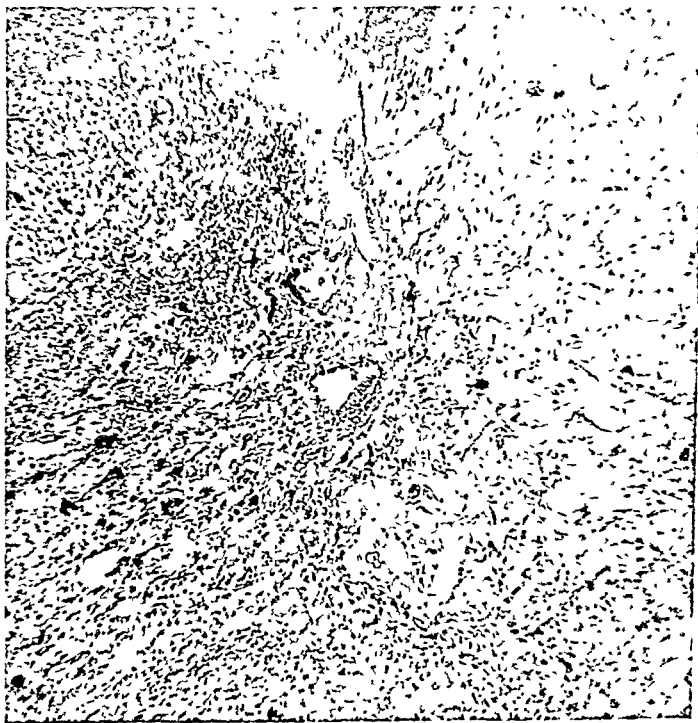


Fig. 2.—A low-power view of one of the metastatic pulmonary osteochondromata.

According to Jaffe,⁷ osteochondrogenic sarcoma tends to metastasize to only one lung more often than osteogenic sarcoma from which the spread is so often bilateral. This observation, if confirmed, is obviously of considerable prognostic significance. The metastatic neoplasms in our case appeared microscopically less malignant than the original lesion, but the possibility that they might be

chondromata arising primarily in the lung, as described by Virchow,⁸ is considered very unlikely. In support of this opinion were the multiplicity of the lesions, the peripheral location of several of the nodules, the relative rarity of multiple primary osteochondromata in the lungs, and the similarity of the metastases to some of the less malignant areas in the original neoplasm (Fig. 2).

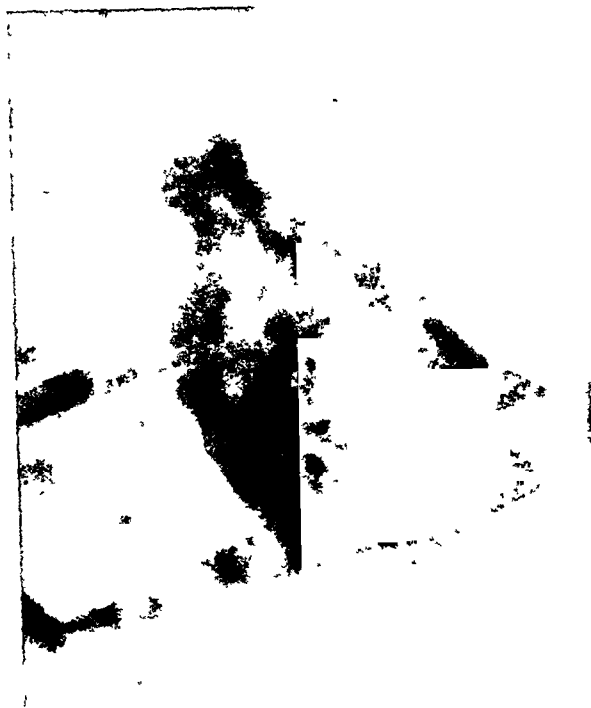


Fig. 3—A rounded shadow is seen just anterior to a vertebral body and superior to the left hemidiaphragm. This proved to be the largest of the six metastatic lesions.

Roentgenology.—The importance of periodically obtaining lateral as well as posteroanterior roentgenograms after the removal of primary neoplasms is emphasized by the fact that even the largest of the metastases in our case did not appear roentgenographically until thirteen years after operation, and then it was visible only in the lateral view (Fig. 3). The radiopaque density within the neoplasm (Fig. 4) led originally to an erroneous diagnosis of a tuberculoma with calcification. In retrospect, the validity of this opinion might well have been questioned because of the history of an amputation having been performed previously for osteochondrogenic sarcoma of the tibia and because of the fact that the deposition of calcium is a nonspecific change which may occur in tissues which are the site of degenerative or inflammatory, as well as neoplastic, changes.^{9, 10}

The roentgen detection of small pulmonary neoplasms presents a problem. Rigler¹¹ states that when favorably situated metastases as small as 2 mm. in diameter have been diagnosed but that small subpleural metastases, which have been demonstrated at autopsy later, have not often been apparent radiologically.

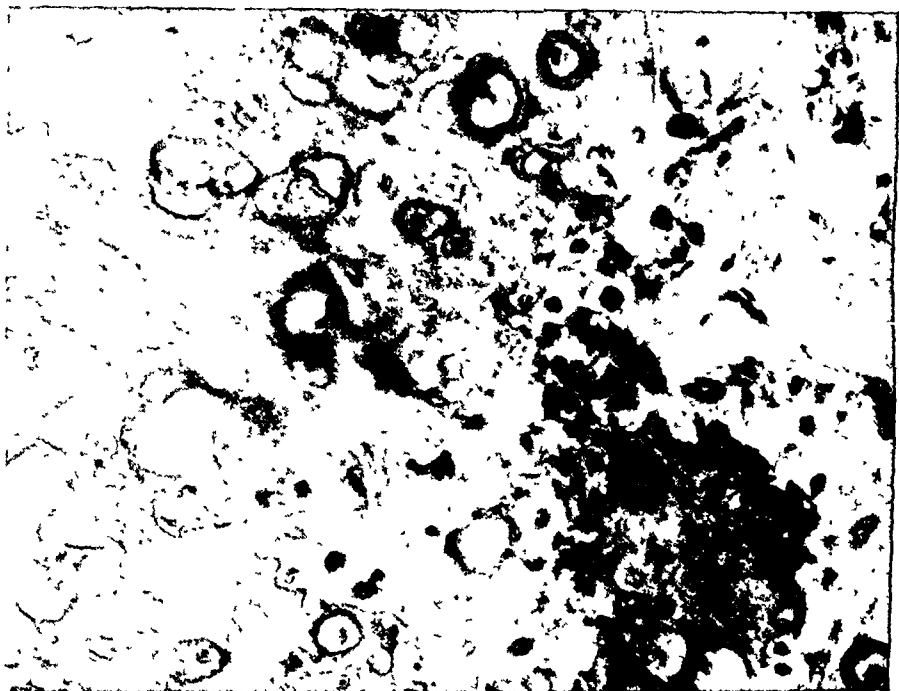


Fig. 4—A microphotograph of a section through the radiopaque density seen near the center of the tumor shown in Fig. 3

In our case, when the preoperative planigrams (made at 2 cm. distance from one another) were reviewed after operation, a second neoplasm was detected for the first time. The other four lesions were not discernible in the planigrams, although the smallest lesion found in the lung at operation measured 4 mm. in diameter.

Treatment.—The only specific reference to a plan of treatment for multiple metastatic neoplasms of which we have knowledge is that of Minor.¹² He advised that the pulmonary lesions should be resected without delay in any patient whose primary lesion had been successfully treated and who had one or more pulmonary metastases so located that they could be resected without removing more than the volume of one lung, and who had no discoverable extrapulmonary metastases. The unexpected discovery at the operation table of six neoplasms instead of one, led to some discussion as to the best course of action in our case. Some of the surgeons felt that the multiplicity of lesions was in all probability indicative of a generalized "seeding" with metastases as yet undiscovered, and that, therefore, resection was not indicated. Also in defense of this opinion was the slowness of growth of the neoplasms already discovered, and the consequent hope that many more years would pass before death.

Resection of the tumors in our case was decided upon because: 1. There was virtually no hope for cure if the metastases were not removed. 2. The patient was a young woman with an otherwise long life expectancy, and for whom the operative risk was small. 3. The results obtained in the treatment of solitary pulmonary metastases of various types (especially sarcoma) have been so encouraging in selected cases that an aggressive policy in regard to multiple metastases seemed warranted. In this respect, fear of the likelihood of the later appearance of pulmonary or other metastases should not necessarily deter the surgeon from resection. A patient described by Alexander and Haight¹³ was free of recurrence twelve years following bilateral pulmonary resections for metastases. 4. The metastases in our case apparently were the cause of pleuritic pain and hemoptysis. These symptoms disappeared after the resection. Seiler and his associates¹⁴ felt that palliative resection for metastatic malignant lesions was occasionally justified. 5. The rare possibility of multiple primary neoplasms of the lung could not be excluded.

Prognosis.—Although the appearance of additional metastases in the lungs or elsewhere is a definite possibility in our patient, especially in view of the microscopic appearance of low-grade malignancy, their not having done so in the two years since the thoracic operation is obviously a hopeful sign.

SUMMARY AND CONCLUSIONS

1. A case is reported in which six metastatic osteochondrosarcomata were removed from one lung fourteen years after a mid thigh amputation for osteochondrogenic sarcoma of the tibia.

2. The patient has been freed of symptoms, and no recurrence has appeared since the pulmonary resections; these were done twenty-four months ago.

3. In selected cases a more aggressive attitude than heretofore employed may be indicated in the treatment of multiple metastatic pulmonary neoplasms.

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Announcement

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The 34th annual meeting of the American Association for Thoracic Surgery will be held May 3, 4, and 5, 1954, in Montreal, Que., Canada. Headquarters will be at the Sheraton-Mount Royal Hotel.

Requests for Hotel Reservations

These should be mailed *directly* to the Reservation Manager, Sheraton-Mount Royal Hotel, Montreal, Que., Canada. Please mention this Association, type of accommodation desired, date, and approximate hour of arrival. If accommodations are desired elsewhere, please communicate directly with hotel of your choice.

Thoracic Surgical Forum

After due consideration, the Council has decided to try an experiment by assigning one morning session to a "Thoracic Surgical Forum" for the presentation of short papers on current thoracic research, anatomy, modified surgical techniques, etc. Papers at this session will be limited sharply to ten minutes (including the showing of lantern slides or other illustrative material) with three minutes as the maximum discussion of each paper.

These papers will be published together in one issue of *THE JOURNAL OF THORACIC SURGERY*. Maximum length: 3,000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts for Papers

Abstracts for the presentation of papers at the 1954 meeting, including papers before the Forum, must be received on or before January 1, 1954, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Forum" or "For Regular Program."

Five, repeat five, copies of each abstract should be sent to the Secretary of the Association, Dr. Paul C. Samson, 2938 McClure St., Oakland 9, Calif. They should not be sent to the Editor.

The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Jan. 1, 1954, to be considered for action in Montreal. Applications received beyond this deadline will be deferred for consideration until 1955.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the sponsoring statement on the application form, the sponsors *must* submit a separate letter concerning the applicant direct to Dr. Lyman H. Brewer, III, Chairman of the Membership Committee, 2010 Wilshire Blvd., Los Angeles, Calif. Completed application forms should likewise be sent to Dr. Brewer. These regulations are at the direction of the Council and were made effective in 1952 at Dallas.

The Journal of Thoracic Surgery

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DECEMBER, 1953

No. 6

Original Communications

THE EXPERIMENTAL CLOSURE OF ATRIAL SEPTAL DEFECTS

HARRIS B. SHUMACKER, JR., M.D., THOMAS C. MOORE, M.D. (BY INVITATION),
AND HAROLD KING, M.D. (BY INVITATION)
INDIANAPOLIS, IND.

IT WAS the object of this study to explore various methods for surgical closure of atrial septal defects and, if possible, to develop a method applicable to human patients. It was our original feeling that the ideal procedure for use in patients would be one which would be applicable to all types and sizes of atrial septal defects, which would give fairly certain assurance of complete closure of the defect, preferably with autogenous tissue, and which could be accomplished in a dry field without loss of blood, without interference with cardiac function, without the necessity of using anticoagulants, and without the hazard of air embolism or intracardiac thrombosis.

Healthy mongrel dogs were used. A large atrial septal defect made through the opened right atrium during momentary occlusion of venous inflow was created in each animal either immediately before the closure or at some time previous to it.¹ Following induction with intravenously administered pentobarbital sodium intratracheal ether-oxygen anesthesia was employed, using an intermittent positive pressure apparatus. The heart was exposed through a long right intercostal incision. Penicillin was given postoperatively for the first week. No anticoagulants were used.

As compared with the situation which one might expect to encounter in human patients, the attempts at surgical closure of atrial septal defects in experimental animals were performed under certain handicaps. If the defect were made some time beforehand, application of the graft was facilitated because the margins of the defect were firm and took sutures well. The pleural

From the Department of Surgery, the Indiana University School of Medicine.

Aided by a grant from the James Whitcomb Riley Memorial Association and a contract between the Office of Naval Research, the United States Navy, and Indiana University.

Read at the Thirty-third Annual Meeting of The American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 30, 1953.

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Two of the three open sides were closed with continuous sutures. The pocket was everted so as to have the smooth inner surface outside. The wire ring was inserted and the remaining open side closed with an inverting suture (Fig. 1, c). Thus both types of graft were covered with smooth uninjured mesothelium. By clamping the ring at one point through the overlying tissue, the disclike graft could be held perpendicular to the long axis of the clamp. A suture was placed opposite the clamp and the ends left long. As soon as the atrium was opened, the graft was placed over the defect and the previously placed suture was passed through the margin of the defect and

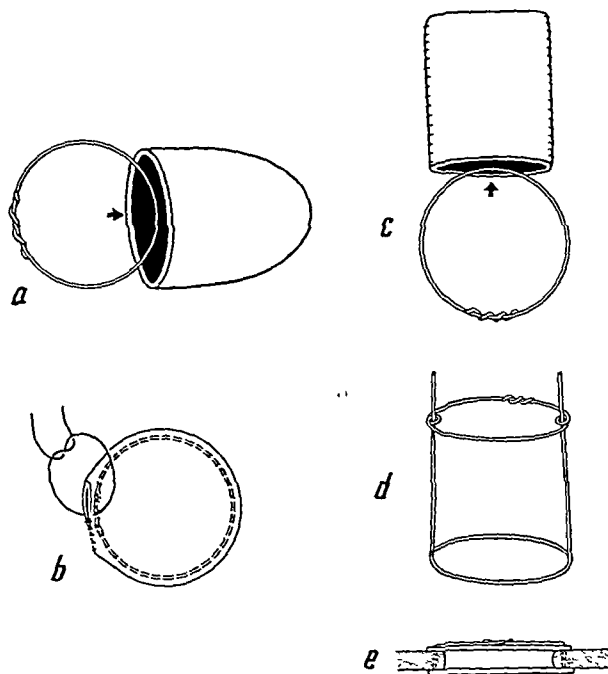


Fig. 1.—Diagrammatic illustration of method of constructing wire ring-splinted grafts of atrial appendage (a and b) and pericardium (c) and method of fixing double onlay graft with wire sutures (d and e).

tied. The suture was then continued around the periphery, fixing the margins of the graft to the edge of the defect. After a brief period the clamp was removed, the suture brought out through the cardiotomy opening which was closed temporarily with a Satinsky or an angulated Potts or Glover clamp, the vena caval obstruction released, and the lungs hyperventilated with oxygen. A complete circular suture could generally be completed during three short periods of vena caval occlusion. The results of such direct continuous suture are exemplified by the following experiments:

Dog 93.—A large septal defect was made during a forty-second period of venous obstruction. A splinted graft of auricular appendage was sutured in place with a continuous suture of fine steel wire during three periods of occlusion of venous inflow of 95, 117, and 158 seconds' duration. Heart action was never properly established after the last period and

and pericardial adhesions from the first operation, however, added to the difficulty of exposure and the previous incision through the atrial wall was particularly troublesome when the method of closure necessitated insertion of a pericardial pocket in the same area. Creation of the defect immediately before its closure eliminated the latter obstacles but the fresh pliable margins of the defect made the suturing of the graft in place somewhat more difficult than would have been the case with a defect of long duration. As a consequence, both freshly created and older defects were utilized, the former particularly in those experiments requiring the fixation of a pericardial pocket to the edges of an incision in the atrial wall.

ONLAY GRAFT THROUGH OPEN RIGHT ATRIAL CHAMBER

This group of experiments was concerned with the direct application of an autogenous graft to the septal defect through the opened right atrium during temporary occlusion of the inferior and superior venae cavae and the azygos vein.

Direct Circular Suture of Graft to Margins of Defect.—Preliminary observations revealed two facts of significance. In the first place, in contrast to the situation with the intact normal heart, the period of safe occlusion of venous inflow into the right side of the heart is markedly shortened if the right atrium is opened at the same time and a graft sutured to the margins of the defect. Templeton and Gibbon² found that systemic venous return to the intact normal dog's heart could be blocked for periods up to nine minutes with survival of the animal. In other experiments dealing with the production of atrial septal defects,¹ we learned that the period of venous occlusion had to be shortened considerably in order to assure survival. Though the safe upper limit was not determined statistically, we cut the period of occlusion to around one minute or less and eliminated fatalities. Similarly, in our early efforts with the grafting of septal defects it was apparent that only a brief interval of obstruction of venous inflow was compatible with survival. In the second place, it soon became evident that unsupported grafts of pericardium or of auricular appendage could not easily be sutured in place during short periods of occlusion. Suturing was time consuming even though the graft was kept flat and taut by traction on the sutures placed equidistantly along its margins. The traction sutures and the clamps attached to them got in the way and reduced the speed of suture.

We therefore resorted to means of splinting the graft. The grafts were made either of auricular appendage or of pericardium. When the appendage was used it was excised completely after clamping its base. The pectinate muscles which joined the two walls were divided and a circular ring of stainless steel wire was inserted into the cavity. The open margins of the appendage at the base were then closed with a continuous inverting suture of 00000 Deknatel (Fig. 1, *a* and *b*).

Pericardial grafts were made in similar fashion. A segment of pericardium of suitable size, rectangular in shape and roughly twice as long as wide, was excised. The pericardium was then folded on itself so as to make a square of double thickness with the external surface of the pericardium exposed.

Other Modifications.—Another method utilized a double pericardial graft, each of which was stretched over a wire ring. To one of the rings were fixed two wire sutures, opposite one another (Fig. 1, *d* and *e*). The other ring had two small loops opposite one another. The first graft was introduced into the atrial chamber and pushed through the defect into the left atrium. The two wire sutures were directed through the margins of the defect and out into the right atrium. They were then passed through the tiny wire loops of the other graft which was pushed down against the defect. The two sutures were quickly tied over this graft so as to hold it snugly against the other with the rim of the defect interposed between the peripheral portions of each. The excess wire was cut away and the cardiotomy closed. The results are illustrated by the following example:



Fig. 2.—Photograph of septum in Dog 191 three months after repair by double onlay wire splinted pericardial graft. The erosion of the wire rings into the atrial cavity is seen.

Dog 191.—A large septal defect was created and repaired at the same operation. The animal was sacrificed three months later. The graft was smooth and firmly united with the septum. The original defect was so nearly completely closed that there appeared to be no functioning defect though actually a tiny opening remained. The wire rings were not visible from the left atrial side. Through the right atrium one could see a small segment of the deeper ring covered with endothelium (Fig. 2). About 40 per cent of the larger ring of the second graft had eroded through. The wire suture over the graft could be seen under a thin endothelial cover. There was no thrombus and no obstruction to the ostia of venae cavae or coronary sinus.

Other measures were employed with less success. For example, a splint was constructed with two cross bars passing at right angles across the ring.

ceased shortly afterward. Post-mortem examination revealed the defect to be tightly closed. There was no obstruction to the ostia of the venae cavae, nor were there any thrombi upon the graft or within the heart.

Dog 94.—A large septal defect was made. In three sessions a splinted circular graft of auricular appendage was sutured in place with a continuous wire suture. The three periods of vena caval occlusion averaged eighty-eight seconds, the total period of occlusion being four minutes and twenty-three seconds. The animal was sacrificed two days later. The graft was securely sutured to the margins of the defect closing it tightly, and no thrombi were present. The wire ring lay within the graft.

Dog 97.—A large septal defect was made. This was followed by suturing in place a splinted pericardial graft with a continuous wire suture during three periods of obstruction of systemic venous inflow of approximately the same duration as in Dog 94. The animal was sacrificed nine months later. The graft was well healed to the septum and the defect was completely closed. A portion of the wire ring projected into the right atrium caudally, lying alongside the posterior portion of the inferior vena caval ostium. There was no obstruction and no thrombi were present.

Fixation of Graft by Sutures Passed Through Septum and Out Through Atrial Wall.—In order to shorten the period required for fixing the graft to the septum, a number of modifications were tried. In some animals, five silk sutures were placed through the rim of the splinted graft, equidistant from one another, and tied. Both ends of one suture were left long. One end of each of the other sutures was cut short while the end to which the needle was attached was left long. As soon as the right atrium was opened, the first suture was passed through the posterior margin of the defect and tied. The other four were then passed through the septum and out through the atrial wall. One suture went through the posterior caudal lip of the defect and out of the atrium under the inferior vena cava. Another passed through the posterior caudal lip of the defect and out of the atrium under the inferior vena cava. Another passed through the posterior cephalad portion of the margin of the defect and emerged underneath the junction of the superior vena cava and the auricular appendage. The other two sutures were directed through the anterior rim of the defect and out through the interatrial groove. A clamp was placed across each suture at the point where it passed out of the atrium in order to keep it taut so the graft would be held in proper position. After closing the cardiotomy opening, each suture was secured by tying it to a fine silk suture passed through the adjacent auricular wall. The results of these efforts are illustrated by the following experiences:

Dog 115.—Closure with an auricular appendage graft was attempted by the method outlined fifteen days after creation of a large defect. The procedure required obstruction to venous inflow for seventy-five seconds. Six days later the dog died of pneumonia. The graft was in place and the defect was closed in large part. The posterior caudal suture had pulled out of the septal margin and a tiny defect had resulted. No thrombus was present.

Dog 117.—Thirty days after the production of a large septal defect it was repaired in the same manner as that used in Dog 115. Forty-six days later the animal was sacrificed. The graft was securely healed to the margins of the defect, closing it completely. There was no thrombus and the graft was covered with smooth glistening endothelium. A small portion of the wire had eroded into the left atrial cavity along the caudal portion of the graft.

INSERTION OF GRAFT THROUGH A RUBBER-CAPPED CYLINDRIC GLASS WINDOW

Glass cylinders about 2 cm. long and of varying diameter were constructed. A ridge was fashioned near either end in order to keep an encircling ligature from slipping off. A piece of rubber dam was secured over one end with a ligature (Fig. 3, *a*). A purse-string suture was placed about the mid-portion

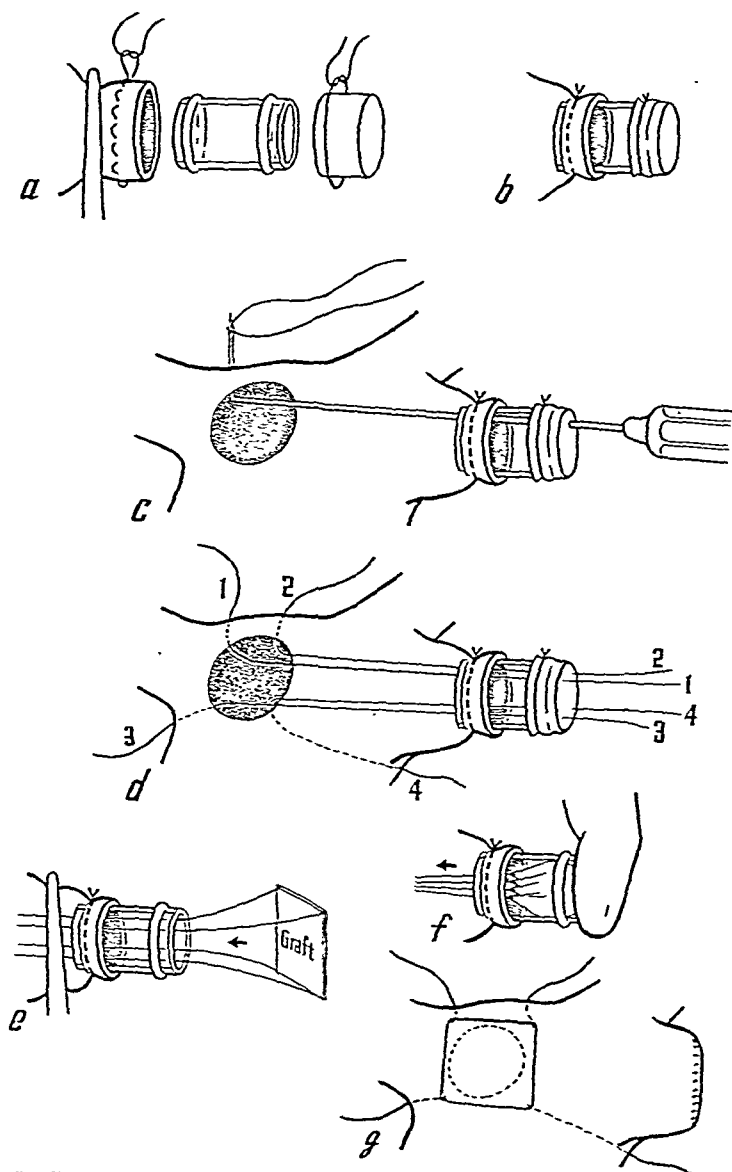


Fig. 3.—Drawings illustrating technique of insertion of graft through rubber-capped glass cylinder. In *a* and *b* the covering of the cylinder with a rubber cap and its insertion into the atrial appendage are shown. In *c* and *d* are illustrated the placement of sutures through the septal rim and atrial wall. *e* and *f* show the pulling of the graft into the atrial chamber without loss of blood; in *g* the graft is in place.

The four ends of the cross bars were twisted about the ring and cut about 4 or 5 mm. long so as to leave four sharp spikes projecting perpendicularly to the plane of the splint. The splint was covered with a graft. The mid-portion where the cross bars intersected was grasped with a clamp. The graft was thrust through the defect into the left atrium and an attempt was made to pull it upward against the septum so that the four spikes would perforate the septal margins. This maneuver was found to be awkward and generally unsatisfactory. Some of the spikes bent and did not perforate the septum. Sometimes one or more would come through properly while others would slip into the defect. Furthermore it was usually not possible to bend them so as to engage the graft firmly to the rim of the defect. Various modifications were tried but none proved satisfactory.

Comment.—It was apparent that the direct application of onlay grafts to atrial septal defects by direct suture during periods of obstruction of venous inflow were attended by sufficient hazards to make its use in human patients unjustified.

The safety of the operation could be increased by various modifications which enabled the surgeon to fix the graft in place during a single brief period of venous obstruction. For those who may attempt such direct repairs through the open atrial chamber, either under conditions of hypothermia or during exclusion of the heart with the use of an extracorporeal pump-oxygenator apparatus, certain of our experiences may prove helpful. First, grafts made either of auricular appendage or of pericardium, so constructed that their external surfaces presented an uninjured smooth mesothelial surface, appeared to be entirely satisfactory in the dog. They united well with the septum and no gross thrombi developed upon them. As will be developed subsequently, however, it is doubtful that large free grafts of the thicker human pericardium or atrial appendage will prove satisfactory and it may be preferable to utilize inert plastic discs. Second, the suturing of free autogenous grafts in place was greatly facilitated by splinting them. Though the circular wire splints used never became completely dislodged and, during the period of observation, never appeared to cause difficulty, they tended in time to erode partially through the graft and to project into the atrial cavity. Perhaps the same end could be accomplished by some absorbable splint such as a fibrin ring or disc. It would probably be preferable to utilize inert plastic discs instead of autogenous tissue. Third, the free circular grafts were more reliably fixed so as to accomplish complete closure when they were united to the margins of the defect by direct continuous suture. Multiple interrupted sutures would seemingly also be satisfactory. The use of multiple sutures tied to the edge of the graft and thrust through the septum and out through the atrial wall reduced the speed of application of the graft and was reasonably reliable though it was more often followed by persistence of small defects. If this method were combined with the use of a few direct sutures of the graft to the margin of the defect the percentage of complete closures would undoubtedly be increased.

serted into the azygos vein as it entered the superior vena cava. In the remainder the cylinder was inserted through the base of the appendage. The attempts at closure were carried out from sixteen to fifty-three days after creation of the septal defect.

The chief obstacles encountered were the occasional crossing of sutures as they were inserted and the difficulty of accurate placement of the two posterior sutures. The results varied. In most of the animals the original septal defect was closed in its anterior portion but the posterior third of the defect remained open. In only one case was complete closure secured. The sutures caused no intracardiac thrombosis and were often not visible at the time of final examination, being buried in the septum. The results obtained are illustrated by the following experiences:

Dog 196.—An atrial septal defect approximately 1.7 cm. in diameter was made. Seven weeks later using a pericardial graft and wire sutures closure was attempted. Before closing the opening in the base of the appendage a finger was introduced into the right atrium and the area of grafting palpated. The posterior sutures had not been placed accurately and the posterior part of the defect was not completely closed. The animal was sacrificed six and one-half months later. The anterior portion of the defect was nearly closed but approximately one-fourth of the original defect was open in its posterior part. The graft was nicely united to the septal wall and was covered with glistening endothelium. The sutures were not visible on the interior of the heart and there were no thrombi.

Dog 199.—Two and one-half weeks after creation of an atrial septal defect approximately 1.8 cm. in diameter, repair was carried out in the manner employed in Dog 196. The heart was examined two weeks later. The defect was closed completely. The graft appeared well united with the septum. There were no intracardiac thrombi.

Comment.—The principle employed has certain virtues. The method permitted the insertion of a graft into the interior of the heart without interfering with cardiac function, without loss of blood, and without apparent hazard of intracardiac thrombosis or air embolism. Use of the base of the appendage for insertion of the cylinder, however, fixed the cylinder some distance from the defect and, in spite of the fact that it could be brought nearer the defect by virtue of the mobility of the atrial wall, made accurate placement of sutures somewhat difficult. It was apparent that the method might be modified to advantage. If the larger glass or plastic cylinder was introduced through the atrial wall near the site of the defect it would appear evident that sutures could be placed with greater accuracy, crossing of sutures avoided, and complete closure more often achieved. Furthermore, a finger introduced through the atrial appendage would facilitate placement of sutures. It is planned to investigate this matter in the near future and to use plastic rather than viable grafts.

CLOSURE OF DEFECT BY USE OF A PERICARDIAL POCKET AFFIXED TO AN INCISION IN THE ATRIAL WALL

The operative technique finally evolved is as follows: A large segment of the presenting pericardium is excised after removing any fatty tissue presenting on its external surface. It is trimmed to a roughly square shape ap-

of the right auricular appendage. The appendage was clamped at its base, the tip amputated, the pectinate muscles divided, and the cylinder fixed in place by drawing the suture taut about its base (Fig. 3, *b*). The clamp was released and blood allowed to flow up into the cylinder. A needle was introduced into the cylinder through the rubber diaphragm and a small amount of heparin solution injected. Air was usually not present in discernible quantity. If present, it would rise to the top of the cylinder and could be withdrawn by aspiration into a syringe.

A modified small aneurysmal needle with the end sharpened and made into a right angle curve was passed through the rubber cap and cylinder into the right atrial chamber (Fig. 3, *c*).

Ordinarily it was easy to locate the defect and to pass the needle through it into the left atrium. By bringing the end of the needle up against the left atrial wall just beyond the septum one could see it push the wall out, feel it, and be certain that it had passed through the defect into the left atrial chamber. It was then passed through the left atrial wall anteriorly near the cephalad margin of the defect. A fine wire or silk suture was threaded onto the needle. One end was held while the needle was withdrawn through the defect, the right atrium and the cylinder.

In succession three other sutures were placed (Fig. 3, *d*), one emerging from the left atrium near the anterior caudal portion of the defect, one through the posterior caudal portion of the defect and emerging from the posterior aspect of the atrial wall near the inferior vena cava, and one through the posterior cephalad portion of the septum and passing out of the atrial wall near the posterior surface of the atrium between superior vena cava and appendage. The cylinder was elevated, the base of the appendage again clamped, the rubber dam removed and stripped off the sutures, the cylinder irrigated with saline solution and the four sutures fixed to the four corners of the graft (Fig. 3, *e*). By drawing up on the various sutures which had been passed through the atrial wall while the clamp was loosened slightly the graft could be pulled down into the glass chamber. The top of the cylinder was then covered with a finger, the clamp released and the graft drawn into the atrium (Fig. 3, *f*) and snugly up against the septal defect. The base of the appendage was then clamped, the glass cylinder removed, and the opening subsequently closed with silk sutures (Fig. 3, *g*). Each of the sutures attached to the graft was fixed to the atrial wall at its point of emergence by tying it to a fine silk suture placed in the atrial wall. The graft could thus be inserted without loss of blood and in no case was clotting a problem, nor air embolism.

This principle was employed with varying success in nine animals. In one the graft was a wire ring-splinted pericardial graft, in two a segment of inverted external jugular vein, in six a pericardial graft constructed in the manner previously described but without a wire splint. Wire sutures were used in seven animals, silk sutures in two. In one case, a modification of the method of placement of the glass cylinder was used, the cylinder being in-

wall snugly against the septum. With practice the posterior wall can be kept in proper position so as to outline the margin of the defect and the excess of the pocket can be kept from ballooning out into the field and obscuring vision. A 0000 catgut suture is then passed through the pericardium and the anterior lip of the margin of the defect. It is tied and continued as a locking suture around the rim of the septal defect (Fig. 5). At the completion of the closure it is tied to the other end of the suture. If desired it can be supplemented by a few interrupted sutures. By its purse-string effect, it not only seals off the defect with the pericardial graft but also reduces the cross-sectional area of the defect. If at the completion of the procedure there is no excess of pericardium, the lungs are inflated and the chest wall closed. In rare instances there is an excess of pericardium. In such cases a portion of the pocket bulges out of the atrium. The protruding pericardium is then clamped, amputated, and the cut margins approximated with a fine silk suture.

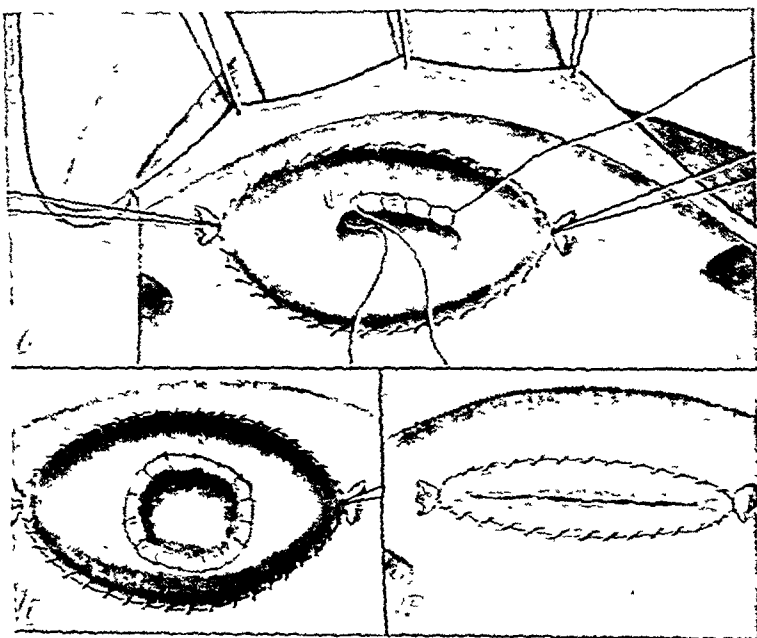


Fig. 5.—Illustration of the method of suturing the posterior wall of pericardium to rim of the septal defect. *a*, The suture is started. *b*, The suture is completed. *c*, Appearance of atrial wall at completion of operation.

In actual practice the defects made were often so large as to leave no rim of septum anteriorly. In such cases the sutures were passed from pericardium out through the left atrial wall immediately adjacent to the interatrial groove and back again through the pericardium. Often, too, there was no palpable rim at the inferior aspect of the defect. In such cases sutures were passed out through the left atrial wall alongside the posterior aspect of the proximal end of the inferior cava and back through the pericardium.

During our early experiences various methods of suture were tried, and various sizes and shapes of pericardial pocket were tested. In some instances

proximately 6.5 cm. in diameter. Care is taken to keep the graft moistened with physiologic saline solution and to avoid injury to the smooth cardiac surface. The square is folded on itself with the external surface outside and each of the two shorter open sides of the resultant rectangular graft are closed with a fine silk purse-string suture (Fig. 4). There results a pocket open at one end.

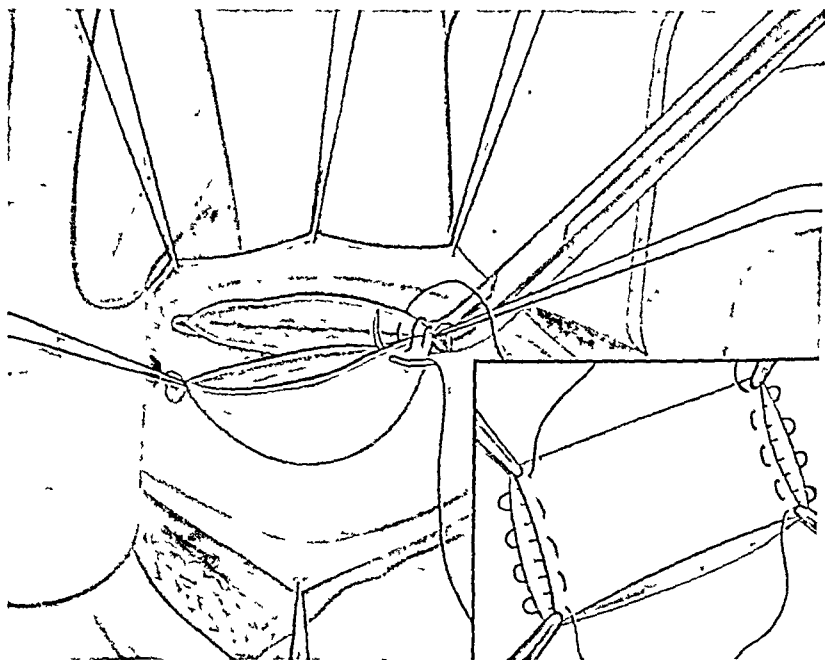


Fig 4—Drawing illustrating technique of construction of pericardial pocket and its fixation to an incision in the atrial wall

Traction sutures are placed in the atrial wall roughly parallel to the interatrial groove, the lowermost suture being in the anterior wall of the proximal end of the inferior vena cava, the uppermost near the end of the superior vena cava, or, in case the heart is small, more cephalad near the base of the atrial appendage. During momentary occlusion of the systemic venous inflow, an incision is made and a defect of the atrial septum roughly 2 cm. in diameter is created. The atrial incision is closed with a modified angulated Glover clamp and the venous obstruction released. The open edges of the pericardial pocket are then sutured to the edges of the incision using a continuous 00000 silk suture interrupted in at least one place (Fig. 4). On release of the clamp the pericardial pocket fills with blood and bulges out. It is now invaginated into the atrial cavity, its smooth and uninjured cardiac surface presenting on the interior of the heart. Its posterior wall is pushed against the septum and the defect can be accurately palpated and outlined. The tip of the left index, and sometimes that of the middle finger, is kept in the pocket and serves both to retract the anterior and to push the posterior

Small silk granulomas were observed between the adherent anterior and posterior layers of pericardial pocket.

For this reason it was decided to employ a catgut suture. These efforts are considered in two groups. The first were made with pericardial pockets of varying size and shape and before we were aware of the extreme importance of utilizing an incision in the atrial wall of adequate length. Closure in this group of nine animals, examined from two to fifty-three days after repair, was either complete or nearly so, residual openings varying in size from 1 to 3 mm. in diameter. The second group of nine dogs was operated upon after the previously described technique had been fully developed. One heart was examined five days, one twenty-nine, and one thirty-seven days after operation. The others were studied from six to seven weeks after repair. Closure was complete in seven while in two a pin-point opening 1 mm. in diameter could be found. Since the results were consistent the series was not enlarged.



Fig. 7.—Photograph of atrial septum of Dog 325, six and one-half weeks after repair of defect as seen from left atrial side. The grafted area is hardly distinguishable from the remainder of the septum.

The operation was tolerated well. In the entire group treated by the inverted pericardial pocket technique there were no immediate operative deaths. In the early experiments there were some deaths later from empyema and pneumonia. Except for these animals, one which was badly injured in a fight with another dog and one which was sacrificed because of cerebral dam-

the pocket was made in a rectangular fashion by closing without purse-stringing the two shorter ends of the overfolded pericardium. In some a triangular pericardial pocket was constructed.

In nine dogs the posterior wall of the pocket was fixed to the rim of the defect by interrupted silk sutures, often fairly widely spaced. The hearts were examined from three to seventy-two days later. In three dogs a fairly sizable residual defect was found, in three dogs closure was complete, while in the others closure was practically complete, the residual defects ranging in diameter up to $\frac{1}{4}$ mm. It is important to remember that when a defect 2 cm. in diameter is reduced to one $\frac{1}{4}$ mm. in diameter the surface area of the opening has been reduced by over 96 per cent and when reduced to one 2 mm. in diameter by 99 per cent.

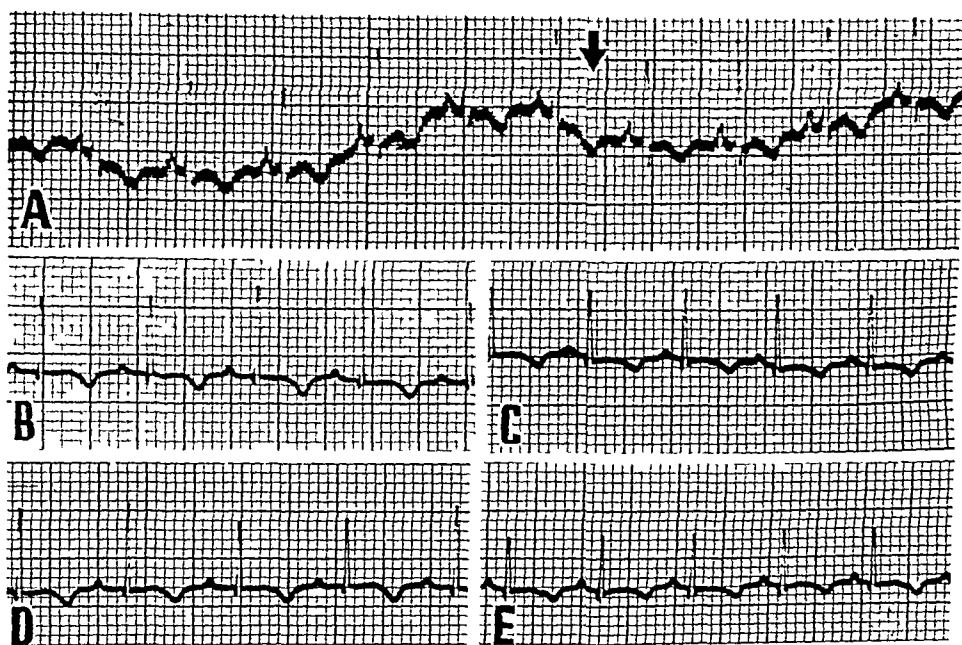


Fig. 6.—Electrocardiographic tracings during operative repair of atrial septal defect by the invaginated pericardial pocket technique. A, Lead II tracing during clamping of atrial wall (arrow) after creating septal defect B and C, Lead II tracings and D and E, Lead III tracings before and immediately after repair of defect.

In four animals the posterior wall of the pocket was united with the margin of the defect with Michele clips applied with a specially designed instrument. One defect was only half closed; in one dog there was a residual opening 4 mm. in diameter, and in two dogs closure was complete. An occasional clip was seen to have eroded partially into the atrial cavity though none was dislodged.

In two dogs a continuous fine silk suture was used. In one animal examined three months later there was a tiny opening 2 to 3 mm. in diameter. Closure was complete in the other which was examined four months after repair.

Comment.—This method seemed highly satisfactory and eminently suitable for use in human beings. Actual experience²⁰ has shown that the procedure is withstood well by patients and that the defect can be securely closed at the time of operation. It has become evident, however, that the pericardium placed over a large defect may disintegrate completely, presumably from failure of sufficiently rapid vascularization of the free transplant. It might be supposed that the method could be successfully modified by employ-

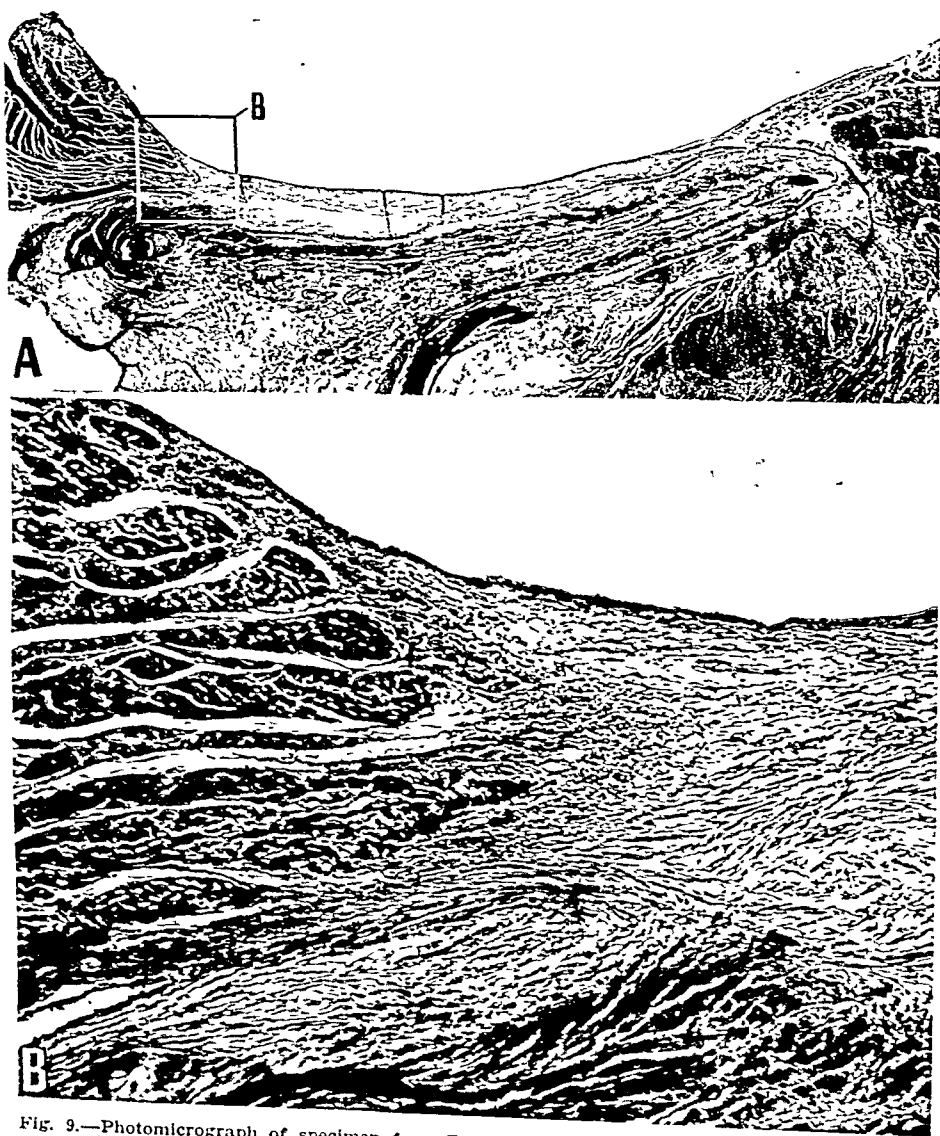


Fig. 9.—Photomicrograph of specimen from Dog 349 showing firm union of pericardial graft and septal wall six weeks after operation. The graft is covered with endothelium.

age suffered at the time of operation while an empty oxygen tank was tardily being replaced, all the animals quickly recovered from the procedure and remained in excellent health. No significant electrocardiographic alterations were noted after making the atrial septal defect, after placing the clamp on the atrial wall, or after repairing the defect (Fig. 6).



Fig. 8—Photograph showing repaired septum in Dog 338, five and one-half weeks after repair as seen from right atrial side. The ostia of the venae cavae and coronary sinus are unobstructed. It can be seen that the original defect was practically complete extending from the inferior to the superior vena caval ostium and down to the floor of the atrium.

The two layers of the pericardial pocket quickly became sealed together. The graft became smoothly fused with the septum. When examined some time after repair the graft was covered with smooth endothelium. Intracardiac thrombi were not observed. From the left atrial side the grafted area was hardly distinguishable from the remainder of the septum (Fig. 7). In no case was there encroachment upon the pulmonary veins. From the right atrial side the thickened area of the pericardial graft was more readily identified. It was covered with smooth endothelium and did not encroach upon the ostia of the venae cavae or coronary sinus (Fig. 8). Microscopically the fibrous tissue of the graft was firmly united with the muscular tissue of the septum and was covered with smooth endothelium (Fig. 9).

than 1 cm. At times thrombosis occurred and occasionally this process completed the closure of a defect which had been incompletely closed by the operative procedure.

Since our own experiments were begun a number of additional reports have been recorded. In 1951 Martin and Essex⁹ described the use in eight dogs of a small polyethylene disc, either bare or covered with an inverted segment of azygos vein. The defects were created immediately before closure was attempted and were made by blind incision of the septum with a knife inserted through the auricular appendage. The discs measured either 1 by 1, or 1 by 2 cm. in size. They were introduced through a small atrial incision after three attached sutures had been passed blindly through the septum and out of the atrial wall. The defects were very small and the authors reported considerable variation in the accuracy of placement of the graft. They abandoned efforts to close defects through the opened right atrium during temporary vena caval occlusion because of the prohibitively high mortality. In the same year Hufnagel and Gillespie¹⁰ reported the successful closure of defects by means of a plastic prosthetic device consisting of two discs which could be secured together, one on either side of the septum. In 1951, Dennis and his associates¹¹ also recorded their fatal effort to close a septal defect through the opened atrium in a patient in whom a pump-oxygenator was used to replace heart and lung function.

The following year Kiriluk, Hoag, and Merindino¹² described the creation through the opened right atrium of large septal defects which tended to remain open during long periods of observation. They attempted closure by three methods: the suture of an infolded segment of auricular wall into the defect, the direct closure by suture of the defect through the opened atrium, and the nonsuture plugging of the defect by a specially constructed pericardial graft introduced through a biauricular approach. The closure was complete in four of six dogs treated by the first method, five of six treated by the second, and three of six treated by the third.

After our studies were completed additional reports appeared in the literature. Cookson, Neptune, and Bailey¹³ recorded experiences with the use of hypothermia in human cardiac surgery. They included a fatal case in which repair of an atrial septal defect was attempted through the opened right atrium. The patient died of ventricular fibrillation. The authors concluded that open operations for closure of atrial septal defects were contraindicated because of the hazard of air embolism.

Subsequently Lewis and Taufic¹⁴ reported the case of a 5-year-old girl successfully treated during a period of hypothermia by direct closure of a septal defect through the opened atrium. They operated upon twenty-six hypothermic dogs for closure of experimentally produced atrial septal defects. One defect was found to have closed spontaneously. Seventeen dogs survived opening the atrium and repairing the defect. There were eight deaths, four from ventricular fibrillation. In two of the latter there was obvious coronary air embolism. Seven additional animals had ventricular fibrillation but recovered. One death occurred in the last ten closures.

ing a pocket of inert plastic material and suturing the incised atrial wall carefully after completing closure of the defect. Such experiments have been initiated. They have thus far shown that the modification is technically satisfactory and is withstood well by the animals. A second modification is also being studied and is similarly technically feasible and well tolerated. This involves direct suture of a plastic disc to the rim of the defect through the invaginated pericardial pocket. Both methods are to be carefully evaluated. The first seemingly is more promising for human application since it eliminates the possibility of intracardiac disintegration of pericardial tissue.

DISCUSSION

Before the studies described were begun a number of reports had appeared in the literature describing surgical efforts to close atrial septal defects produced experimentally in animals or occurring spontaneously in human patients. In 1947 Cohn¹ made small atrial septal defects by passing a clamp *into the left atrium through the appendage, thrusting it blindly through the septum, and opening the blades of the instrument.* The auricular wall was subsequently invaginated into the right atrial cavity, fixed to the margin of the defect by one or two sutures, the tip of the invaginated portion severed by a wire snare, and the opening in the atrial wall closed by drawing taut a previously placed purse-string suture.

In 1948 Murray² reported that he had closed atrial septal defects in about thirty dogs by passing sutures in the line of the interauricular septum *beginning at the site of the transverse sinus behind the aorta and coming out posteriorly between the superior vena cava and the right pulmonary veins in such a way that when two, three, or four such sutures were pulled taut the anterior and posterior atrial walls were compressed together and the defect occluded.* The size of the defects was not mentioned. He described one patient who had improved following this procedure.

In 1949 Dodrill³ recorded his experiences with the use in dogs of a specially designed clamp which permitted compression of the right and left atrial walls against the septum. By this means he was able to excise segments of the septum and to repair them by direct suture approximation of the cut edges or by suturing the rim of the defect to the left atrial wall.

Santy and his associates⁷ described, in 1950, the plugging of a small septal defect in a patient by inverting the tip of the left auricular appendage through it. In the same year Swan and his associates⁸ reported efforts to close defects in dogs made by direct excision of a portion of the septum through the opened right atrium. They inverted both the right and left atrial appendages by tightening a silk suture which had been passed from the right to the left appendage through the atrial chambers and the defect and onto which were threaded two circular buttons of stiff polyethylene, each of which was then invaginated into one of the appendages. This operation was carried out upon ten dogs, eight of which were examined after they died or were sacrificed. The defects were rather small, only one of them being of greater diameter

than 1 cm. At times thrombosis occurred and occasionally this process completed the closure of a defect which had been incompletely closed by the operative procedure.

Since our own experiments were begun a number of additional reports have been recorded. In 1951 Martin and Essex⁹ described the use in eight dogs of a small polyethylene disc, either bare or covered with an inverted segment of azygos vein. The defects were created immediately before closure was attempted and were made by blind incision of the septum with a knife inserted through the auricular appendage. The discs measured either 1 by 1, or 1 by 2 cm. in size. They were introduced through a small atrial incision after three attached sutures had been passed blindly through the septum and out of the atrial wall. The defects were very small and the authors reported considerable variation in the accuracy of placement of the graft. They abandoned efforts to close defects through the opened right atrium during temporary vena caval occlusion because of the prohibitively high mortality. In the same year Hufnagel and Gillespie¹⁰ reported the successful closure of defects by means of a plastic prosthetic device consisting of two discs which could be secured together, one on either side of the septum. In 1951, Dennis and his associates¹¹ also recorded their fatal effort to close a septal defect through the opened atrium in a patient in whom a pump-oxygenator was used to replace heart and lung function.

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Swan¹⁵ has recently described his clinical experience with the use of the method of biauricular invagination previously developed in experimental animals. One patient died and two survived the operation. In both the surviving patients postoperative cardiac catheterization studies were disappointing since a significant left-to-right atrial shunt was still present. A modified procedure was utilized in two patients, both of whom lived and in both of whom the defect was estimated to have been about 80 per cent closed. A finger introduced through the right atrial appendage was used to guide two sutures from the left auricular appendage through opposing edges of the defect and out through the incision in the right appendage. A plastic button threaded onto these sutures was pushed into the right atrium after momentarily withdrawing the finger. A second button was threaded onto the sutures outside the left appendage and thus the left appendage and the button in the right atrium could be brought together against the septal defect.

Bailey and his associates¹⁵ had found Swan's original method unsatisfactory. One patient went steadily downhill after an attempt at closure and was reoperated upon for removal of the buttons. He died two days later. Another who underwent mitral commissurotomy as well as closure of an atrial septal defect did not survive. A third died thirteen days after operation. Post-mortem examination revealed the defect to have been only partially closed. No healing had taken place between the invaginated appendages and the rim of the septal defect. Two patients survived operation but had persistent evidence of atrial shunt. Because of these experiences another procedure was proposed. Using for guidance a finger introduced through the right atrial appendage the right atrial wall was sutured to the rim of the defect. Two patients were so treated with success.^{15, 16}

Gross and his associates¹⁷⁻¹⁹ have recently described their experiences with a method of repair involving the use of a large rubber well which is sutured to the atrium. The auricular wall is incised and blood flows up into the well. Intracardiac manipulations are carried out by palpation through the pool of blood. Clotting is prevented by intermittent addition of heparin to the blood in the well. Using this procedure closure was carried out in sixty-eight dogs by suture application of auricular appendage, vein or pericardial grafts, by onlay grafts of plastic material sutured to the defect, by nonsuture application of Hufnagel-Gillespie plastic buttons and by direct suture closure of the defect. The results were highly satisfactory, the closure being complete in sixty animals and residual defects being 4 mm. in diameter or less in the remainder. Seven patients were operated upon. In three, plastic buttons were used. All died. In three, nylon or polyethylene was sutured to the defect. Two survived. In one patient, who did well, a small defect was closed by direct approximation of its edges, a second defect by suturing its rim to the atrial wall.

In spite of these varied and excellent contributions it would seem fair to conclude that no method thus far described is ideal.

Our studies have revealed several facts of interest. The experiments with direct application of overfolded segments of atrial appendage or of pericardium

demonstrated that such grafts are entirely suitable in the dog, unite firmly with the septum and do not cause intracardiac thrombosis. It is doubtful, however, whether such free autogenous grafts will prove satisfactory for the closure of large defects in human beings. The introduction of grafts through the opened atrium during momentary occlusion of venous inflow was found compatible with survival but was considered too hazardous for use in patients.

The likelihood of survival was related to the speed of application. The period of necessary vena caval occlusion could be shortened by carrying out the process of suture in stages with several short rather than one longer period of venous obstruction and by several modifications which increased the rapidity of fixation of the graft. The experiences with the use of a rubber-capped glass chamber introduced into the base of the appendage showed this method to be safe and unattended by hazard of air embolism or intracardiac thrombosis. The position of the chamber somewhat distant from the defect resulted in some difficulty with accurate placement of sutures and suggested the likelihood that fixation of a larger chamber in the atrial wall near the defect might overcome this trouble. Such a modification is to be studied in the near future.

The technique involving the use of an invaginated pericardial pocket gave satisfactory results and after the most careful evaluation seemed entirely suitable for use in human beings. It appeared to fulfill the requirements of the ideal operation. It does not interfere with cardiac function, is accomplished in a dry field without loss of blood, uses autogenous tissue, permits direct suture of graft to the rim of the defect, entails no need for anticoagulants, and seemingly is without danger of intracardiac thrombosis or air embolism.

Experience with one patient, however, has demonstrated that the pericardial pocket, when placed over a large defect may be resorbed and literally melt away.²⁰ Experiments are now under way in which the same technique is being employed utilizing a pocket of inert plastic material instead of pericardium. It is hoped they will prove successful and provide a method suitable for the repair of defects in patients.

CONCLUSIONS

Experiences with several methods for the surgical repair of atrial septal defects have been described. One method in which a graft is inserted through a rubber-capped glass cylinder into the atrial chamber and fixed to the rim of the septum without blood loss appears capable of modification to overcome its present deficiencies. Another technique involving the use of a pericardial pocket invaginated into the atrial cavity seemed entirely suitable for use in human beings. Actual experiences in patients having shown, however, that the pericardial graft may melt away from the area of the defect, it is apparent that autogenous pericardium is unsuitable and it is suggested that the same general technique utilizing an inert plastic pocket may prove satisfactory.

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DISCUSSION

DR. CHARLES P. BAILEY, Philadelphia.—I have certainly enjoyed this paper, but would like to present a method which we have used on a number of human beings.

(Slide.) This method has been described as atrio-septo-pexy and has been reported in the *Annals of Internal Medicine*. The operator's ungloved left index finger is inserted through the right atrial appendage to guide the passage of the suturing needle.

(Slide.) Here you see the sutures being placed and the greatly dilated right atrial wall being invaginated and accurately sutured to the periphery of the defect.

(Slide.) That results theoretically in reduction of the great atrial chamber to a doughnut-shaped chamber, the defect being bridged by a portion of the normal right atrial wall.

(Slide.) However, sometimes with a large defect you have to use up half the doughnut and just preserve a passageway for the superior vena caval flow to the remainder of the formerly dilated atrium.

(Slide.) In cases complicated by associated mitral stenosis, the finger should be passed through the defect and either a digital or a digitally guided incisional commissurotomy should be performed. Then the defect should be closed.

(Slide.) In cases with associated anomalous pulmonary venous drainage, the defect will not be a central one but will be located close to the mouths of these veins, posteriorly. It is then possible to suture the redundant atrium to the septum in such a way that two compartments are created from the right atrium. The smaller drains the anomalous pulmonary venous flow through the defect into the left atrium; the larger one drains the two venae cavae through the tricuspid valve.

(Slide.) These are our results in defects of the septum secundum. In fifteen human beings we had two with associated mitral stenosis and five with anomalous pulmonary drainage who were treated as just described. The mortality was 13.3 per cent. Marked clinical improvement was obtained in all survivors. Eight cases have been catheterized postoperatively and six have been shown to have complete abolition of the shunt.

We have done this also in seven cases of persistent ostium primum. One of those was done only two days ago; that is a short follow up, but the patient seems to be in pretty good shape. We have lost three patients with persistent ostium primum, one because of unwise use of hypothermia, one because of postoperative anuria, and one because of the poor condition of the patient. We now know, however, that the defect can be completely closed by this technique.

It seems to us that this is a very simple surgical procedure which can be easily applied in nearly all cases with this condition.

DR. EARLE B. KAY, Cleveland.—I have employed essentially Dr. Bailey's technique in the closure of atrial septal defect in eight patients, and would like to review this experience with you. Four of the eight patients had complete absence of the atrial septum. The septal defect varied from 1.5 to 3 inches in diameter. In three of the patients the septal defect was incomplete and measured 1 to 1.5 inches in diameter. In one patient the defect was very large but fenestrated. The patients ranged from 9 to 49 years of age. Two of the patients had an associated Lutembacher syndrome.

(Slide.) The first slide demonstrates the auricle after it has been invaginated and sutured to the rim of the septal defect. In those patients in whom there is complete absence of the septum, a little ridge remains at the site of the septum that can be palpated. The suture is inserted through the wall of the enlarged right auricle, through this rim of residual septum and then out through the auricular wall in a manner similar to a purse-string suture, or individual sutures from an anteroposterior direction may be employed. The two patients with an associated mitral stenosis had the commissures opened by finger traction inserted through the right auricle and septal defect.

(Slide.) The next slide demonstrates the largest giant auricle encountered. The right auricle measured over 4 inches in diameter and the septal defect measured 3 inches in diameter. The auricular wall was largely replaced by scar tissue so that their technical difficulties when associated with a rheumatic myocarditis were more serious.

(Slide.) This demonstrates the postoperative appearance of the right auricle after it has been invaginated and used to close the septal defect in this patient.

(Slide.) This slide demonstrates a postoperative angiocardigram. The doughnut configuration of the right auricular chamber after invagination of the auricular wall is apparent.

In this series of eight patients there were three deaths. One of these was the patient previously demonstrated who had a Lutembacher syndrome associated with a giant right auricle. This patient, as well as the other two who died, had evidence of arterial desaturation.

The problem of the management of the patient with atrial septal defects who develops evidence of arterial desaturation deserves special emphasis. As a result of the increased pulmonary blood flow, increased pulmonary arterial tension is present. This may manifest itself in two ways. The increased pressure causes atheromatosis changes in the pulmonary vascular bed as demonstrated in the present slide. Often these changes are greater in the smaller pulmonary arteries and arterioles than in the capillaries. This further increases the pulmonary resistance and in turn the pulmonary arterial pressure. At this stage the increased pulmonary blood flow from the atrial septal defect may be necessary to assure proper oxygenation. Should the defect be closed, and the blood flow reduced, cyanosis may develop or increase. Furthermore, as the pulmonary pressure increases, the pressure within the right

ventricle increases and, in turn, the pressure within the right auricle may increase to the degree of causing reversal of flow, i.e., a right-to-left shunt may develop and be responsible for unoxygenated blood getting into the systemic circulation.

The two patients with evidence of arterial desaturation who died had right ventricular and pulmonary arterial pressures of 95 and 125 mm. of mercury, respectively. The arterial oxygen concentrations showed 83 and 89 volumes per cent. All three of the patients died within a period of four to five days of increasing respiratory failure and cyanosis. Autopsies in all three cases showed evidence of thrombosis of the main pulmonary arteries which was interpreted as being the result of increased pulmonary tension and stasis of blood flow.

(Slide.) The next slide presents the results of the cardiac catheterization studies by Dr. Henry Zimmerman of another patient with an atrial septal defect in whom evidence of reversal flow or, in other words, a right-to-left shunt could be demonstrated. This patient was a 13-year-old girl who had been cyanotic for one year. As you see, the pressure within the right auricle was 10 mm. of mercury and that within the left auricle was 5 mm. of mercury.

As experience increases, the lower level of arterial desaturation compatible with a successful outcome will be known.

DR. C. WALTON LILLEHEI, Minneapolis.—As has been indicated, a large number of methods are available for closure of atrial septal defects at the present time. However, none of these methods appears so safe or so satisfactory that one would care to recommend it for routine application to patients who are getting along quite satisfactorily, since obviously still better methods will become available in the very near future.

However, in those patients who have a large interatrial septal defect, and who are having trouble from congestive heart failure or from diminished cardiac reserve, it seems imperative to undertake surgical correction by one of the currently available methods. In choosing the best operation for such a patient there are several objectives that seem to us worthy of emphasis. The first of these is the necessity for closure under direct vision. I think that few surgeons in the audience will dispute the fact that palpation is frequently a poor substitute for vision, and thus, surgical procedures carried out under direct vision are far more likely to be satisfactory than those carried out blindly. This is particularly applicable to cases of interatrial defects.

In our own observations, a surprising number of these defects are multiple and lie scattered around the more inaccessible periphery of the septum and may be contiguous with the orifices of the venae cavae making blind closure hazardous of obstruction of these structures. Further, although occasional atrial defects are found in the center of the septum with a nice margin of tissue around them, unfortunately there is no way that I know of to predict such favorable types ahead of time. Moreover, other atrial defects are of the septum primum type in which the lower margin abuts directly upon the valve. In such a case if the closure procedure is done blindly, one of two complications is very likely to occur: either incomplete closure, or serious if not fatal interference with function of the atrioventricular valves.

And finally, as has been indicated today, many investigators have paid considerable attention to the development of various methods of closure of septal defects utilizing tissue grafts, autogenous or homologous, or prostheses of various kinds made of polythene or various other foreign substances.

Aside from the fact that the success of such methods is distinctly dubious, there remains the very important consideration that the use of such grafts or prostheses is quite unnecessary in closing either atrial or ventricular septal defects provided the heart is empty of blood at the time of closure.

These defects are best closed by direct suture of their contiguous tissue margins. In our observations, the edges of even the largest possible defects such as septum primum types literally fall together, if the stitches are pulled up or tied at a time when the heart is emptied of blood and thus its walls are flaccid. This is manifestly true, because the abnormal shunt has produced a compensatory enlargement of one or more of the adjacent chambers. In fact,

it is quite conceivable by consideration of Starling's law and other mechanical factors involved that the cardiac reserve would immediately benefit by having some of this "slack" taken up by direct suture at the time of closure of large defects.

With these criteria in mind, and with an attempt to retain simplicity, I should like to suggest, with some temerity, still another method for closure of atrial defects which fulfills some of these objectives although it is as yet untried clinically.

(Slide.) This method combines the use of an atrial well, as described by Gross for easy and repeated entrance into and out of the heart, together with intermittent vena caval occlusion to allow direct intracardiac vision in a relatively dry field.

In actual operation, the conical rubber well is sutured circumferentially to the right atrial wall. Tapes are placed around the superior and inferior venae cavae and then each is threaded through a short piece of rubber tubing. Quick and positive occlusion is obtained by pulling up on the tapes, and is maintained by crossclamping the rubber tubing with a hemostat.

(Slide.) Air embolism, in our experience, has been best controlled by threading a catheter into the left atrium through a pulmonary vein branch (this vein may be tied off without harm at the conclusion of the procedure). This catheter is connected to a pressure bottle containing sterile 5 per cent glucose for rapid filling of the left side of the heart. In addition a Satinsky clamp is placed through the transverse sinus, and the outflow tract of the heart is occluded proximal to the orifices of coronary arteries during the period the heart is empty of blood and contains air.

(Slide.) After preparations as indicated, the wall of the heart within the well is incised. Blood comes up within the atrial well to a height equal to the interatrial pressure. However, we customarily have used a well considerably more shallow than that described by Gross. Such a shallow well is technically easier to work through, and any tendency to overflow during rest periods is readily controlled by partial vena caval occlusion.

Experiments in our laboratory (Surgical Forum 1952) have indicated that four minutes of complete vena caval occlusion is entirely safe in dogs. In actual practice we have thought it best to work two and one-half to three minutes; then if we are not finished with the suturing, the venae cavae are released after filling the left side of the heart with glucose from the pressure bottle and then releasing the outflow clamp. Two or three minutes are then allowed for the heart to recover and the entire procedure may be repeated.

By this method of intermittent vena caval occlusion with an atrial well, we have obtained as much as thirty minutes of working time within the heart in a dry field successfully in the dog. Obviously, most intracardiac procedures at present do not require nearly that much time.

DR. SHUMACKER (Closing).—I am sure we have all enjoyed the interesting discussions of Dr. Bailey, Dr. Kay, and Dr. Lillehei. They certainly demonstrate the variety of approaches which are presently being investigated and a certain degree of success which is being achieved. I think that it is still worth while to explore other methods in the search for the operation which may ultimately prove to be the safest and the best.

SURGICAL TREATMENT OF MITRAL INSUFFICIENCY

AN EXPERIMENTAL STUDY

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NEW HAVEN, CONN.

INSUFFICIENCY of the mitral valve remains a major problem in the surgical treatment of valvular heart disease. A readily performed and physiologically sound corrective procedure is needed for those patients who are found to have mitral insufficiency as the predominant lesion. We have investigated the effect of a plastic prosthesis, placed in the left ventricular chamber, upon the pathologic physiology of mitral insufficiency.

MATERIAL AND METHODS

Experiments were conducted on twenty-six mongrel dogs which were subjected to thirty-eight operations. Early in the series there were six operative deaths associated with anesthesia and technical difficulties.

The experiments may be divided into two groups. In the first group, an effort was made to place a plastic ball encased in a pericardial tube between the mural leaflet and the endocardial surface of the lateral ventricular wall. There were ten of these experiments. In the first seven, the prosthesis occupied a poor position in relation to the mural leaflet or failed to penetrate completely the myocardium. With further experience it was possible to introduce the pericardial encased ball through the ventricular wall so that it consistently came to rest in the recess behind the center of the mural leaflet. The ventricular incision was made obliquely, in the direction of the muscle fibers, parallel and anterior to the descending portion of the circumflex left coronary branch, 1 cm. below the atrioventricular sulcus. With these landmarks as guides, subsequent mural leaflet balls were readily placed in proper position. The animals were sacrificed at postoperative periods ranging from two months to one year.

In the second group of eight experiments, a longer pericardial tube was fashioned allowing the ball to penetrate further into the ventricular chamber. This permitted the prosthesis to swing to and fro synchronously with the directional changes in blood flow, approximating a ball valve mechanism. This maneuver was performed in four animals as an acute experiment. It was performed in four other animals as a survival experiment under aseptic conditions, and these animals were sacrificed at intervals ranging from five days to two months.

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We then attempted to produce mitral regurgitation and immediately to correct this defect by insertion of the pedicled ball valve. In some experiments regurgitation was produced by incision of either the mural or septal leaflet. In other cases the margin of the mural leaflet and its chordae tendineae were sutured to the ventricular wall. The degree of regurgitation was assessed both by the operator's finger within the left auricle and by pressure tracings obtained through a polyethylene catheter connected to a recording electromanometer. In one experiment regurgitation was created, the pedicled ball inserted, and the animal sacrificed at the end of five days. Initial exploratory cardiotomy in another animal revealed pre-existing mitral insufficiency. The pedicled ball valve was inserted and this animal was sacrificed at two weeks.

Electrocardiographic tracings were obtained on many of the animals before, during, and after surgery.

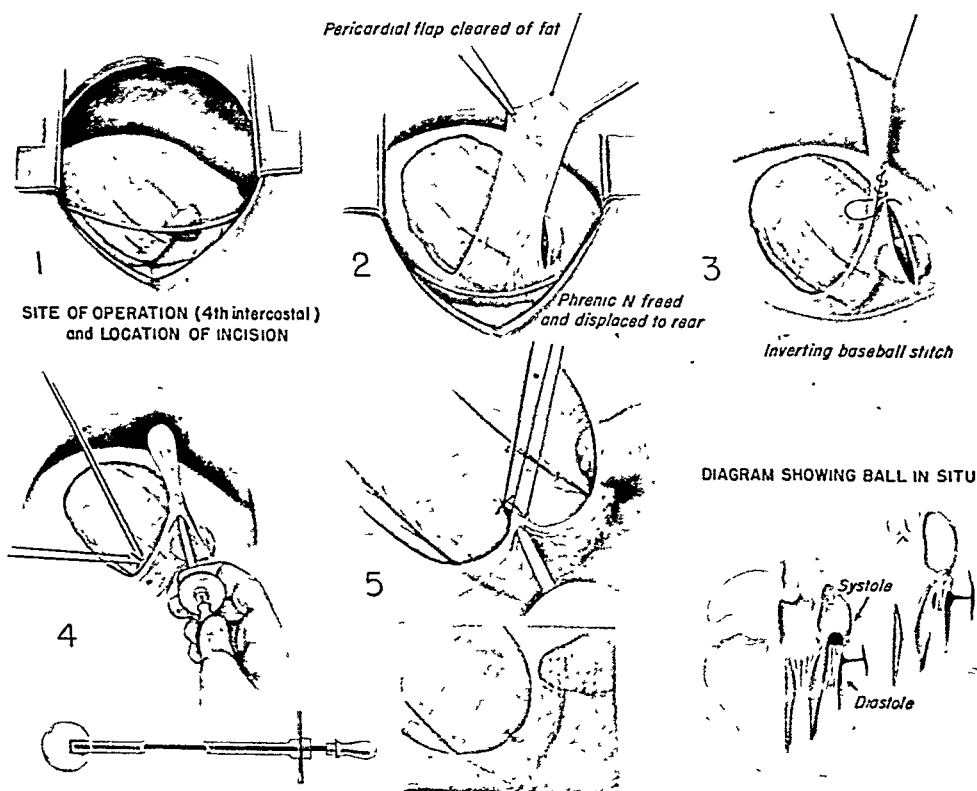


Fig. 1.—Artist's drawings of operative technique. Inset A (left) shows positions of pedicled ball during systole and diastole. Inset B (right) shows stationary ball as buttress.

TECHNIQUE

The dogs were anesthetized with intravenous Nembutal, and intermittent positive pressure oxygen was administered by an endotracheal tube. The left hemithorax was entered through the fourth or fifth intercostal space and polyethylene manometric tubing was placed

in the left auricle through a small pulmonary vein. The phrenic nerve was freed from the pericardium and a rectangular pericardial flap was cut with its pedicle located at the base of the left auricular appendage (Fig. 1, 1 and 2). This preserved the blood supply to the flap through its base since the pericardial vessels' course obliquely in this area. This flap, measuring approximately 5 by 8 cm., was folded and closed to form a pedicled tube with the cardiac surface on the outside (Fig. 1, 3). An inverting baseball stitch was used to minimize silk presenting on the surface of the tube. Two parallel sutures of 0 braided silk on atraumatic needles were then placed in the myocardium of the left ventricle at right angles to the atrioventricular sulcus, anterior to the circumflex branch of the left coronary in its descending course. The inferior ends of these sutures were tied and placed in a clamp held by the assistant. The nylon ball, impaled on the cannula type inserter, was placed in the pericardial tube.

A 1 cm. incision penetrating the ventricular chamber wall was made between the sutures in a direction parallel to the course of the myocardial fibers. The ball and pedicle were then inserted through the incision into the ventricular cavity and the remaining suture ends tied (Fig. 1, 4 and 5). One or two additional myocardial sutures were usually required to achieve hemostasis. A palpating finger was then placed in the left auricular appendage using standard mitral valvulotomy technique and the position of the ball confirmed. The lung was expanded and the chest closed. Antibiotics were not used in these experiments. At sacrifice the intra-auricular pressure was recorded and digital palpation was performed.

RESULTS

In the early cases, where the short pedicled ball was placed as an immobile buttress behind the mural cusp, transauricular palpation confirmed the buttressing effect but there was no indication that the dynamics of the valve had been changed. Palpation in an animal with a longer pedicle revealed a type of ball valve action, the ball being in the mitral ring during ventricular systole, and in the ventricular chamber during diastole. When the pedicle was still longer, there was prolapse through the mitral orifice during ventricular systole. Neither mitral stenosis nor regurgitation was identifiable by the palpating finger following insertion of the ball in the normal heart.

Gross examination of the hearts after sacrifice confirmed the localization of the prostheses previously noted by the palpating finger. It was noted that the long pedicles allowed prolapse of the ball through the mitral orifice into the auricle (Fig. 2). No instance of intracardiac thrombosis, endocarditis, or rupture of a pericardial pedicle was observed.

After inspection of the removed hearts in the freshly opened state they were formalin-fixed in toto. Tissue blocks for microscopic study in all cases were cut from both mitral leaflets, the pericardial investment of the ball and the ventricular wall including the transmyocardial pedicle of pericardium. The following microscopic observations were made. There were no significant changes in valve leaflets. Myocardial healing had occurred with minimal reaction although foci of cartilaginous metaplasia were occasionally seen.

In all but one case, the pericardial pedicle had been converted into a dense collagenous scar. The pericardium investing the ball was thinned, collagenous, and practically avascular. The one exception showed a few endothelial-lined, blood-filled channels coursing longitudinally through the pedicle. The pericardial elements had retained their identity, but in its most dependent portion the pericardial investment of the ball was thinned to a degree where viability



Fig. 2—Photograph of heart opened through the tip of the left ventricle showing pedicled ball valve protruding below central portion of the mural leaflet. The aortic outflow tract at the left is separated by the septal leaflet from the mitral inflow tract at the right. An area of hemorrhage on the superior surface of the pericardial encased ball was the result of vigorous palpation at sacrifice (animal sacrificed at two months)

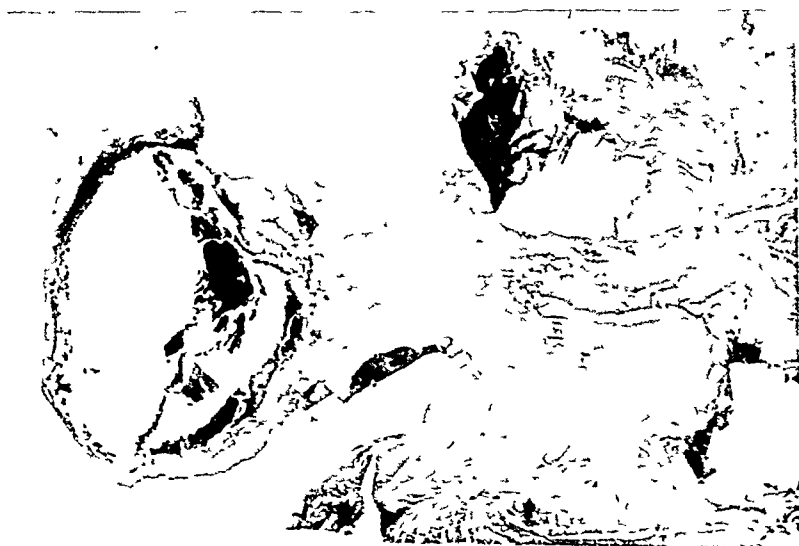


Fig. 3—Photomicrograph (X6) showing pericardial covering at left with pedicle passing through ventricular wall at right. Note extreme thinning at far left and poor vascularity in the entire pericardial tube (animal sacrificed at two weeks)

might be seriously questioned (Fig. 3). These findings suggest that avascular necrosis, rupture of the sac and extrusion of the ball might have followed if the animals had been allowed to survive for a longer period.

Serial electrocardiograms revealed transient ventricular rhythms with S-T and T-wave changes during the operative and immediate postoperative periods. These findings were compatible with the pattern of pericarditis and with focal areas of myocardial damage. The electrocardiogram usually reverted to normal during the first postoperative week.

Neither mitral stenosis nor regurgitation was observed following insertion of the ball in the normal heart.

Intracardiac finger palpation revealed gross regurgitation after incision of either mitral leaflet. This was more marked when the septal leaflet was incised. Manometrically there were marked increases in the amplitudes as well as in the mean auricular pressures. Similar though less marked regurgitation patterns were obtained when sutures were placed through the ventricular wall to include the mural leaflet or its chordae tendineae.

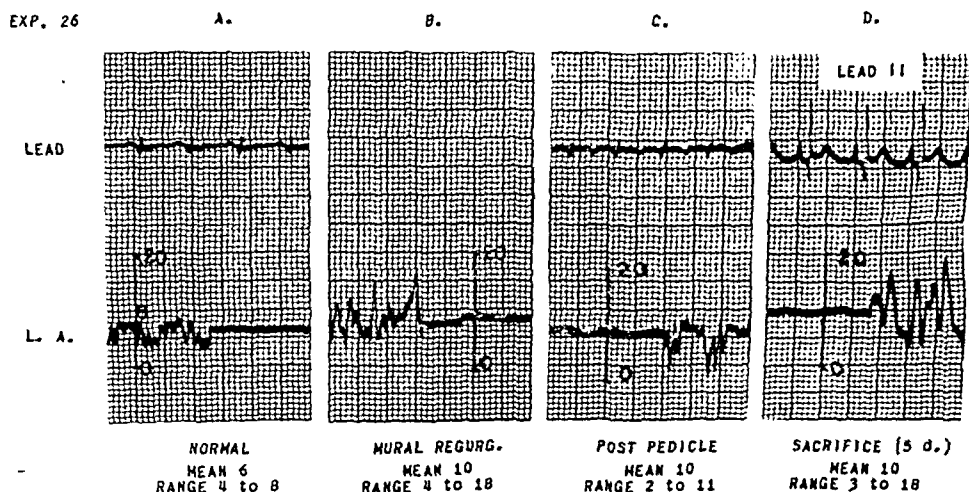


Fig. 4.—Simultaneous electrocardiographic and left auricular pressure tracings from Experiment 26. *A*, Normal preoperative findings with a mean of 6 mm. Hg. *B*, Tracing after incision of mural leaflet creating 1 with mean pressure measured at 10 mm. Hg. *C*, Tracing immediately after insertion of pedicled ball. Mean pressure remained at 10 mm. Hg. *D*, Tracings obtained at sacrifice operation five days later showed no change in pressures.

One animal demonstrated pre-existing mitral regurgitation at initial exploratory cardiomy. This was identified by a systolic thrill over the left auricle and an easily palpable regurgitant jet. In spite of this jet, the mean auricular pressure was normal. This mean pressure was not changed by the pedicled ball valve although the shape of the pressure curve was modified. The jet, which was palpable before insertion of the prosthesis, was no longer present after insertion, nor was it present two weeks later at sacrifice, although the externally palpable thrill remained.

Mitral regurgitation, secondary to incision of the mural leaflet, exhibited a changed pressure pattern after insertion of the pedicled ball valve, although there was no change in either the mean pressure or the pressure range (Fig. 4). In this experiment, the palpable external thrill and the regurgitant jet were unaltered by the insertion of the pedicled ball valve. The jet and thrill were noted again at sacrifice, and palpation revealed the ball approaching the mitral orifice during ventricular systole but not prolapsing into the auricle. The ball was released from the overhanging mural leaflet by digital manipulation and allowed to prolapse into the auricle. This produced marked change in the pressure pattern and complete abolition of the palpable jet. The mean auricular pressure fell from 12 mm. of mercury to 8 mm. of mercury and the range from 13 mm. of mercury without prolapse, to 45 mm. of mercury with prolapse (Fig. 5). These changes were reversed by restoring the pedicled ball to its original position. The observations and tracings were confirmed by repeating the maneuvers several times.

EXP. 26 (2)

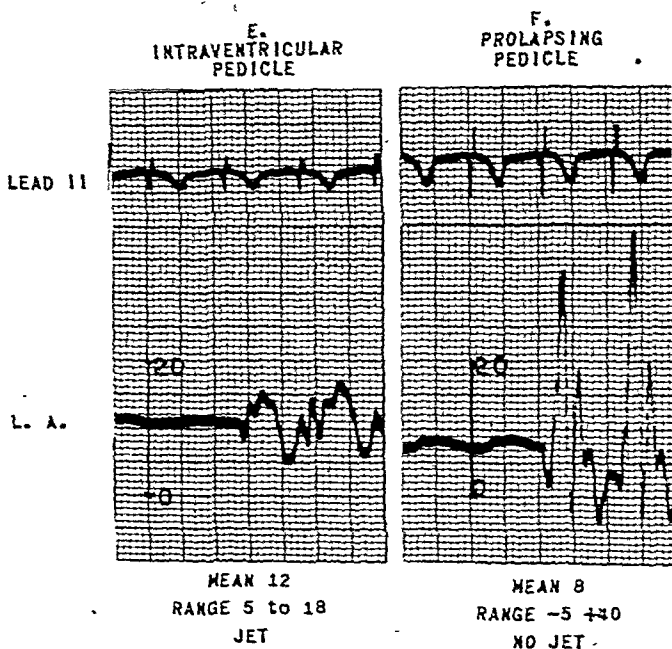


Fig. 5.—Continuation of simultaneous electrocardiographic and left auricular pressure tracings obtained at sacrifice operation in Experiment 26. E, A palpable jet was noted when the pedicled ball remained in the ventricular cavity and the mean pressure was 12 mm. Hg. F, Note reduction in mean auricular pressure to 8 mm. Hg and high pressure low volume waves of the prolapsing pedicled ball valve. Regurgitant jet was no longer felt.

DISCUSSION

Previous investigators have reported auricular wave patterns in experimental animals, normal human beings, and patients with mitral valve disease.¹⁻³ Quantitative evaluation of mitral regurgitation is difficult. Our own investiga-

tions suggest the inaccuracy of the palpating finger as a quantitative measurement of mitral regurgitation. This is implied by the observation of a palpable jet in one experiment which disappeared following the pedicled ball valve operation without an associated change in mean pressure or a significant change in pressure pattern. Other observers have noted that a large mitral opening during ventricular systole allows marked regurgitation with no palpable jet.^{4, 5} However, it is frequently assumed that the degree of regurgitation is roughly proportional to the force of the jet. Our experiments cast doubt on this assumption.

These experiments further confirm the observations of Shumacker and his co-workers that autogenous tissue transplants such as vein, fascia, or pericardium are unsatisfactory for intraventricular use.^{6, 7} We were disappointed that our pericardial pedicles showed early evidence of conversion to avascular collagen. In more than one instance there was sufficient attenuation of the pericardium surrounding the ball to suggest imminent rupture of the sac.

Nevertheless, our physiologic observations suggest that a moving prosthesis placed on the ventricular side of the mitral orifice may function as a tampon during ventricular systole to prevent regurgitation without creating stenosis during ventricular diastole. This suggests a rational basis for the "bottle baffle" operation of Harken.⁸ We do not profess to have produced mitral regurgitation that is identical with that found in rheumatic heart disease. However, it does seem reasonable that mitral regurgitation which is physiologically similar to that found in rheumatic heart disease can be produced in the experimental animal. Valid observations can then be made which will permit development of a method for physiologic evaluation of human mitral regurgitation and the changes produced by operation upon the mitral valve.

SUMMARY

1. Plastic ball prostheses have been placed in the left ventricle adjacent to the mitral valve in a series of animal experiments. This has been done in normal animals as well as in animals with surgically produced, and in one case, naturally occurring mitral insufficiency.

2. No change was observed in the left auricular manometric pressure pattern of normal animals in which the plastic prostheses were used. Significant pressure and wave pattern changes were observed in animals with previously created mitral insufficiency following the insertion of pedicled balls.

3. The accuracy of intracardiac finger palpation in determining the volume of regurgitant flow is questioned.

4. The viability of an intraventricular pericardial pedicle is doubtful even when the pericardial flap is carefully cut to preserve its normal blood supply.

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DISCUSSION

DR. CHARLES P. BAILEY, Philadelphia.—We, too, have been interested in the problem of mitral regurgitation, either spontaneous or created in the course of performing mitral commissurotomy. I think if we could work under direct vision upon the incompetent mitral valve, every one of us would immediately suture together the incompetent portion which is usually located posteriorly. This can now be done by a closed technique.

(Slide.) The left index finger, ungloved, is introduced through the left atrial appendage to guide the passage of this special threaded suturing probe. The tip of the probe punctures the left ventricle at a point guarded by purse string and tourniquet. Guided by the intra-cardiac finger it punctures one valve leaflet at the point desired, follows the finger until it appears at the opening in the appendage so that one side of the suture can be grasped. That is withdrawn and the probe is pulled back. It is disengaged from this leaflet and is immediately redirected, punctures the opposite leaflet and again follows the finger. The opposite side of the suture must then be grasped, and then the probe can be withdrawn from the heart.

(Slide.) You see now that the double suture runs through both left heart chambers and each extremity pierces one of the valve leaflets in the usually posterior incompetent portion.

(Slide.) We now replace this silk suture with a strip of pericardium, a living suture, because we feel that the silk would eventually cut through the valve substance. By traction upon the ends of the silk suture emerging from the ventricle, we can then draw the loop of pericardium completely into the heart until the extremities appear out of the ventricular puncture wound. The finger can at once tell whether there is an appreciable change in the jet of regurgitant blood and frequently can recognize that it is completely abolished by this maneuver. If so, these pericardial ends are attached securely to the ventricular epicardium by sutures. If, however, there still remains appreciable regurgitation, the loop is converted into a noose by making an eye in one end and passing the other end through it. By pulling on the free end, this noose goes up to the valve and not only approximates but actually overlaps the two valve leaflets. Usually one such pericardial suture will greatly reduce the regurgitation, but if necessary a second can be placed. Obviously the free end has to be attached to the epicardium securely to maintain tension. If you reduce the opening too much, or have stenosis in association, a commissurotomy must be performed at the opposite anterior competent commissure.

We have had the opportunity of doing this on 70 or more patients since August, 1952. We have had a mortality, unfortunately, of approximately 25 per cent; this mortality rate was partly due to poor selection of very sick patients, and poor surgical technique during the developmental period. Recently, we have done very much better and have usually been able to completely or almost abolish the regurgitation without endangering the patient. We have had dramatic improvements in many of the patients who have survived. The pericardial graft I do not think does quite as badly as Dr. Shumacker has suggested in other conditions. After three or four months, if an autopsy is performed, the graft is seen to be pretty well welded and fibrosed to both leaflets so that they are glued together permanently. It does not seem as if the pericardium would dissolve.

DR. HARRISON BLACK, Boston.—There are several comments I would like to make on Dr. Carter's paper and the possible application of this method in human beings. This

report is based on work on Dr. Dwight E. Harken's service in Boston. The work began several years ago with animal experimentation at the Boston City Hospital and is being continued now with clinical material at Peter Bent Brigham Hospital.

Before considering the correction of any lesion we should know something about the pathology involved. We have therefore studied the lesion (mitral insufficiency) at the autopsy table in the museum, and at the operating table and have evolved a morphologic classification. On this first slide (slide) are represented the two primary types of *free* mitral insufficiency. Type I results from an absolute *loss of substance* due to scarring and shortening of the valve leaflets, predominantly the aortic, from direct rheumatic damage. There may be associated shortening of the chordae, but the predominant defect is insufficient leaflet length. Type II is the result of *dehiscence of the annulus* and consists of a relative loss of substance in the leaflets. This may occur due either to cardiac dilatation in failure or rheumatic carditis. It is probable that almost all cases of *free* mitral insufficiency fall into one or the other of these categories or the two may be combined, damage of leaflet preceding annulus dehiscence. It must be emphasized that all the patients upon whom we have operated for mitral insufficiency have been of these types of free insufficiency; there was not the slightest suggestion of stenosis. Furthermore, it is fundamental to an understanding of the condition to realize that in pure insufficiency as we have seen it, the leaflets are not calcified but are freely flexible. The defect is due solely to a failure in approximation.

(Slide.) This demonstrates three other types of insufficiency. Type III is the *directional* form resulting from a stenotic funnel facing out into the aortic outflow tract. Since the stenosis is predominant and the insufficiency relatively insignificant, correction entails merely the relief of stenosis. Type IV is due to *malocclusion* in heavily calcified, clumsy, stenotic valves in which irregularity of the leaflet edges prevents a competent watertight closure, and a ribbon-shaped regurgitant jet results. This may produce a noisy murmur, but it is not physiologically important and, again, correction of the predominating stenosis is the present treatment of choice. Finally, in Type V we find a *mixed type of process* in which there is the pathology of mitral stenosis in one area (leaflet fusion and/or calcification) while in another there is loss of substance without any trace of calcification. It is this type that is described by Dr. Bailey, if I understand his remarks about fracturing commissures before correcting insufficiency.

(Slide.) An understanding of the pathology of free mitral insufficiency makes it clear that adding substance to the defective leaflet has been the cornerstone of our corrective efforts. By such a method the mobile leaflets are given an opportunity to approximate something in systole and create a relatively sufficient valve. Dr. Carter has pursued a similar line of reasoning, but there are several reasons why we have discarded any thought of using the transventricular method of placement of the prosthesis. In this slide is shown in cross section the enormously dilated left ventricle we have encountered in cases of free mitral insufficiency. In the first eight patients we placed a Lucite ball beneath the ventricular leaflet via the auricular appendage and sutured it to the ventricular wall. We accepted only frankly terminal patients for this procedure, because we feel that in the developmental stages of any operation the surgeon is morally justified in accepting only this type of risk. These patients survived from one day to eight months, but it was obvious that not enough had been done to correct the insufficiency. At post-mortem examination all revealed that the prosthesis was well tolerated without damage to the myocardium, but because of the deep concavity beneath the leaflet formed by the dilated ventricular wall, the prosthesis was not close enough to the insufficient orifice to implement the loss of leaflet substance. Use of the approach through the ventricular wall would have the same defect, I believe, because it would be impossible in these immensely dilated hearts to place the sphere close enough to the valve orifice to be effective. The second objection to the transventricular approach is that in these dilated hearts the ventricular wall is thin and of poor quality due to congestive failure and chronic rheumatic carditis. In these we have often had difficulty controlling blood loss through the tiny needle sites in the myocardium and would despair of closing a hole large enough to allow the passage of a baffle.

There is one other point of fundamental physiologic importance that I should mention. If you will look at the sketch of the freely insufficient valve you will see that the flexibility of the valve leaflets allows them to balloon upward in a normal manner in systole. Although they do not approximate, the effective orifice is considerably narrower than in diastole when the leaflets wall aside and allow ventricular filling. This change in orifice size is an absolute necessity for the maintenance of forward flow of blood. If a fixed orifice exists or is produced by a technique which tenses the leaflets, the pressure gradients between ventricle and auricle would result in a lethal reversal of flow even if the heart rate were infinitely slowed and diastole infinitely prolonged.

The insert shows what we have done for the last twenty-one patients with free insufficiency. All were accepted for operation only because their outlook was considered hopeless on standard methods of medical management. A Lucite or nylon baffle, shaped like a bottle, has been placed beneath the minor leaflet and held firmly to the ventricular wall with one suture coming out above while the second comes out below the leaflet. The diagram illustrates the mobile aortic leaflet fallen aside during diastole allowing ventricular filling. In systole we have observed that the aortic leaflet approximates the baffle. That some correction has in fact occurred has been demonstrated several times by a rise of blood pressure by as much as 50 mm. Hg immediately after placing the baffle. The striking clinical improvement seen in several patients provides incontrovertible objective evidence that this effort is in the right direction.

We have recently had to reduce the size of the baffle since some have appeared to overcorrect the insufficiency as the annulus and ventricle have approached more normal size. There have been nine deaths. Three deaths were technical in nature. Three related to overcorrection by baffles that produced stenosis when the annulus came down in size in response to the correction of regurgitation. Two patients simply were too ill or too little benefited to survive, much less show improvement. One patient had embolization of the baffle eight months after operation. There are twelve patients surviving of the twenty-one who have had the present operation, and although these results are obviously not brilliant, they are sufficiently encouraging to justify further efforts.

DR. CARTER (Closing).—I have been fascinated, as I am sure you all have been, by the brilliant technical results presented by both Dr. Bailey and Dr. Black. I shall not argue the merits of each method. It does seem to me that the absence of an accepted standard procedure is at least some evidence that the final answer is not yet here. If I may be permitted the temerity of a suggestion, however, I personally would be much happier if instead of showing us human beings, they could show us well-documented long-term follow-ups on some animals, that would let us know exactly what is going on inside these hearts.

PULMONARY VALVULOPLASTY UNDER DIRECT VISION USING THE MECHANICAL HEART FOR A COMPLETE BY-PASS OF THE RIGHT HEART IN A PATIENT WITH CONGENITAL PULMONARY STENOSIS

F. D. DODRILL, M.D., EDWARD HILL, M.D. (BY INVITATION), ROBERT A. GERISCH, M.D. (BY INVITATION), AND ARAN JOHNSON, M.D. (BY INVITATION)
DETROIT, MICH.

BY CONGENITAL pulmonary stenosis is meant the stenosis of the pulmonary valve or infundibulum without overriding of the aorta. Tetralogy of Fallot is not, therefore, the subject matter of this manuscript. It is not an uncommon disease. Although the instance is not exactly known, the clinicians, who routinely carry out cardiac catheterization in congenital heart disease, are finding unsuspected cases.

The exact anatomic defect as well as the hemodynamics is a variable factor. The majority of patients with obstruction to the outflow of the right ventricle have defects in either the interatrial or interventricular septum, although there are some patients without other defects aside from the stenosis itself.

The stenosis may be purely valvular, in which case there is usually a protrusion of excess tissue out into the pulmonary artery, as is illustrated in Fig. 1. With cardiac catheterization, there is a very abrupt change in pressure at the valve area (Fig. 2). The stenosis also may be at the base of the valve cusp or in the infundibular region. Moreover, we have encountered patients with stenosis of both the valve and infundibulum. In such a patient, one finds with cardiac catheterization that the pressure is highest in the lower portion of the ventricle, with a much lower pressure in the infundibular region and finally a lower than normal pressure in the pulmonary artery (Fig. 3).

Some patients have been seen as infants, showing marked cyanosis, only to have this completely disappear at 1½ to 2 years of age. Concomitant with the disappearance of cyanosis, there has been a rapid increase in size of the right heart. Obviously such a change is due to a closure of a right to left shunt, most probably, patency of the foramen ovale.

With obstruction to the outflow of blood from the right ventricle and without a septal defect, there is usually a greatly elevated pressure in the right ventricle which is not uncommonly 175 to 180 mm. Hg or even higher. If there exists a septal defect, the pressure in the right ventricle is dissipated toward the left side of the heart, and there exists, therefore, a right to left

From the Research Division of Harper Hospital.

Aided by a grant from The Michigan Heart Association.

The Mechanical Heart used here was constructed by the Research Laboratories Division, General Motors Corporation.

Read at the Thirty-third Annual Meeting of the American Association for Thoracic Surgery, San Francisco, Calif., March 27, 28, and 30, 1953.

shunt. This produces arterial oxygen unsaturation which, if severe enough, is manifested by cyanosis, polycythemia, and mild clubbing of the digits. In some patients with pulmonary stenosis and a defect of the interventricular septum, the pressures may be essentially equal in both ventricle (Fig. 4). In such a situation, there exists a defect of the interventricular septum without significant shunting of blood through it, the pressures in the two ventricles having equalized. If there exists, therefore, no arterial oxygen unsaturation and if angiocardigraphy fails to show simultaneous opacification of the left heart and aorta, there exists no right to left shunt. Mild degrees of arterial oxygen unsaturation could be associated with a low pulmonary artery pressure.

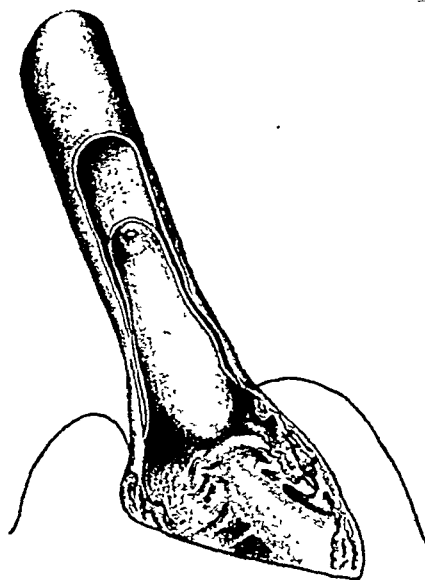


FIG. 1.—Diagrammatic sketch of congenital pulmonary valve stenosis.

This does not necessarily mean that there is no defect present. We have observed one patient at autopsy a few years ago who had a slitlike opening in the interventricular septum which did not permit a right to left shunt, but would permit a left to right shunt provided the pressure in the right ventricle was lower than that in the left. This patient had been studied by cardiac catheterization. It showed a pressure of 140 mm. Hg in the right ventricle and an arterial oxygen saturation of 90 volumes per cent.

A blind procedure has been developed by Brock¹ for the relief of congenital pulmonary stenosis. This consists in inserting a valvulotome through the right ventricle and out through the stenotic pulmonary valve. Undoubtedly this is a good procedure and has vastly improved many patients throughout the world. There are some indications, however, that as time passes the pressure in the right ventricle may again become elevated.² Even though the pressure again becomes elevated, there seems to be clinical improvement of

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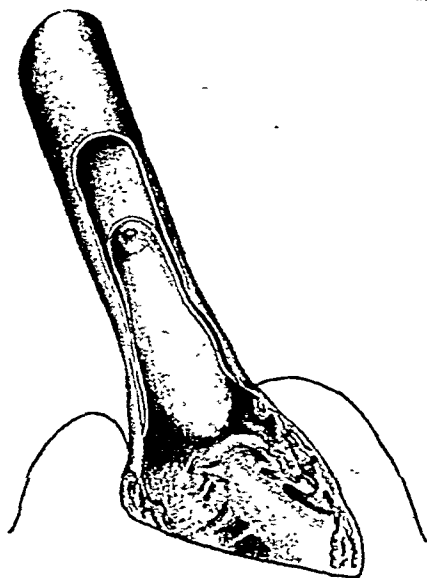


Fig. 1.—Diagrammatic sketch of congenital pulmonary bowel stenosis.

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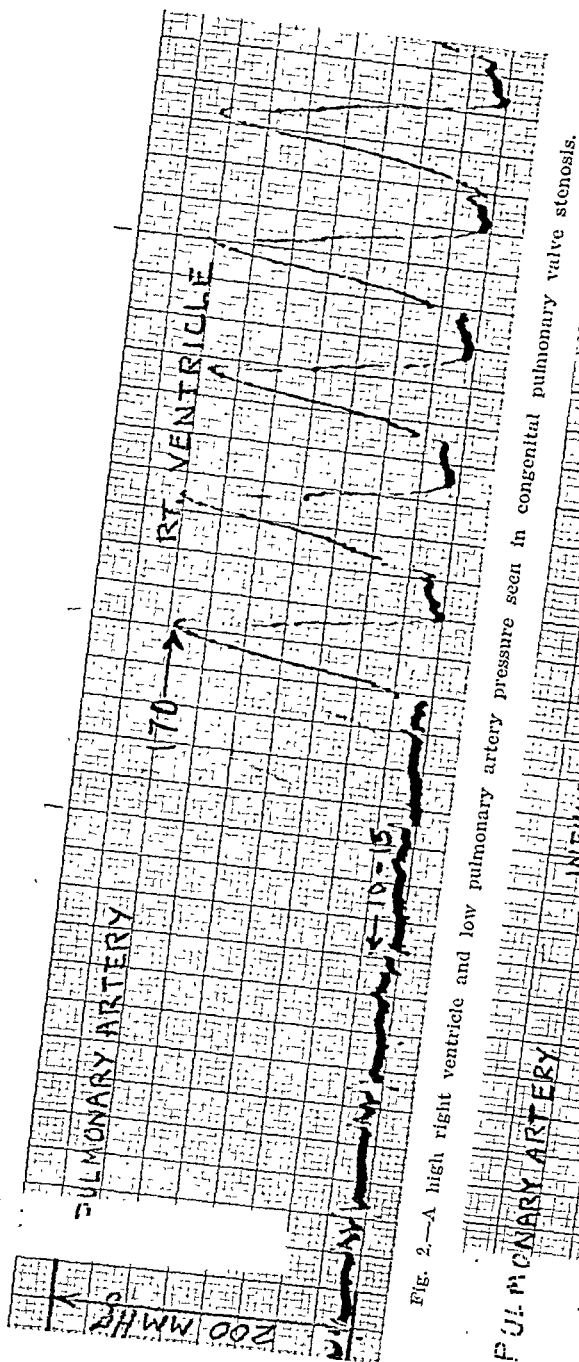


Fig. 2.—A high right ventricle and low pulmonary artery pressure seen in congenital pulmonary valve stenosis.

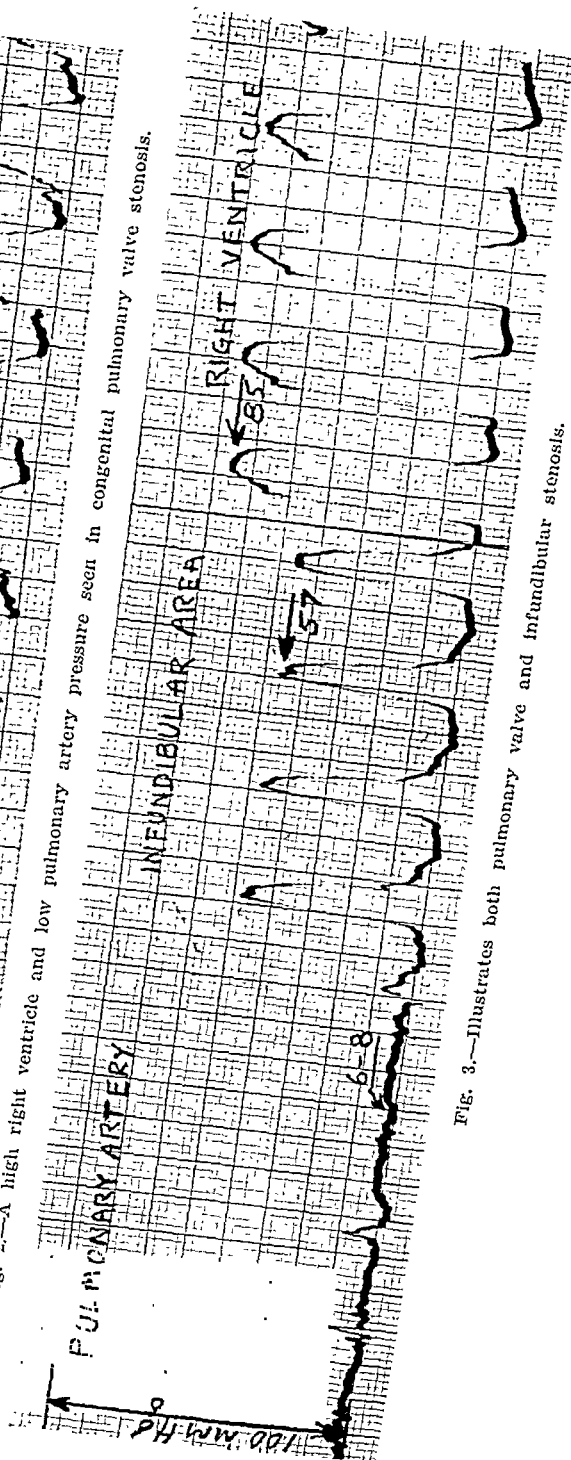


Fig. 3.—Illustrates both pulmonary valve and infundibular stenosis.

the patient. The elevation of the right ventricular pressure is not due to a left to right shunt through a possible interventricular septal defect, since this could be demonstrated by cardiac catheterization.

If the valvular architecture exists, as is illustrated in Fig. 1, and if such a valve is cut with the valvulotome, there is no assurance that the incision may not heal, producing the original obstruction. This is not definitely known.

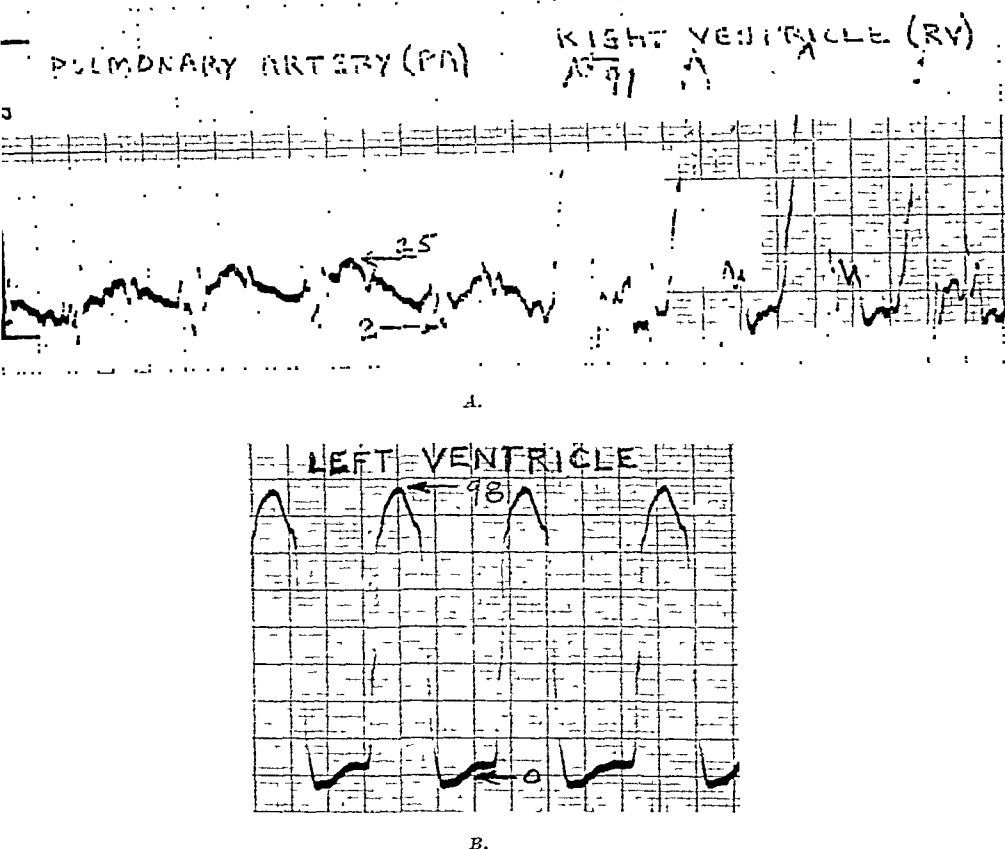


Fig. 4.—Illustrates (A) a high right ventricle pressure and (B) a catheter was passed through an interventricular septal defect where arterialized blood was withdrawn. The pressure in the left ventricle is essentially the same as in the right.

More time must elapse and more cardiac catheterizations must be made on these patients one year or longer after the operation in order that it may be clarified. Although much good has been accomplished by blind procedures within the heart, it is probable that advancement from this point on must be made by exposure of the anatomic structure. With this thought in mind, the mechanical heart has been applied to a patient with congenital pulmonary stenosis. The right heart was completely by-passed. The main pulmonary artery was clamped off for twenty-five minutes while the left heart and lungs continued to perform their functions. The pulmonary valve was exposed and

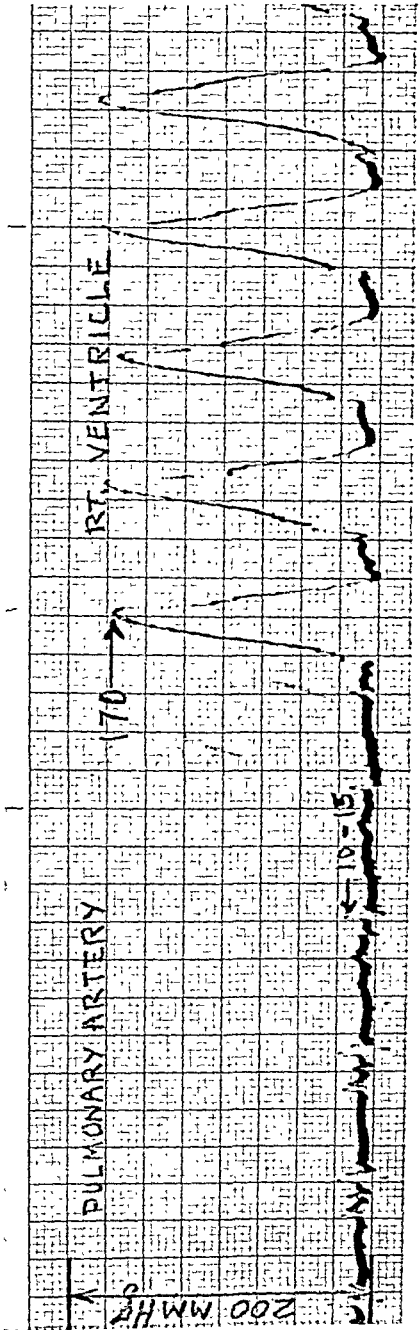


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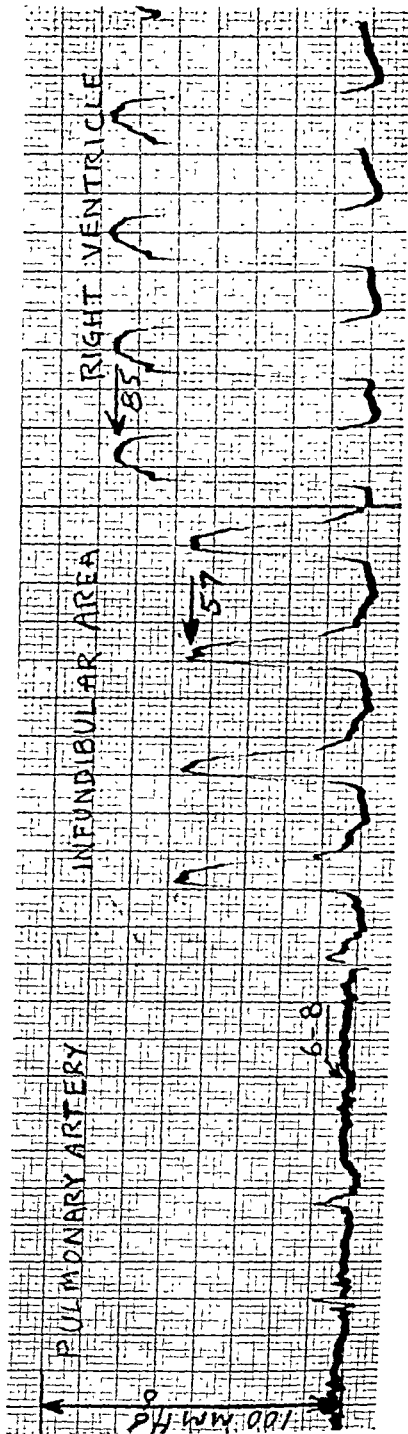


FIG. 3.—Illustrates both pulmonary valve and infundibular stenosis.

of normal; the clotting time was 13 minutes. X-ray examination of the thorax as well as fluoroscopy showed the right side of the heart, especially the right atrium, to be greatly enlarged. The main pulmonary arteries were hugely dilated. There were no visible pulsations of the pulmonary vessels seen at fluoroscopy.

The electrocardiogram showed marked right axis deviation and right ventricular hypertrophy. Cardiac catheterization revealed a pressure in the right ventricle of 190/0 mm. Hg. Preoperatively the pulmonary artery could not be entered. The pressure in the right atrium was 10 to 12 mm. Hg. Blood samples taken from the right ventricle, right atrium, and superior vena cava showed similar oxygen content, 15.87 to 16.83 volumes per cent. The arterial oxygen saturation was 90 volumes per cent.

Since this patient had a high ventricular pressure and since there was no cyanosis or significant arterial unsaturation, he obviously did not have a right to left shunt. The arterial oxygen saturation of 90 volumes per cent could be accounted for on the basis of low pulmonary artery pressure.

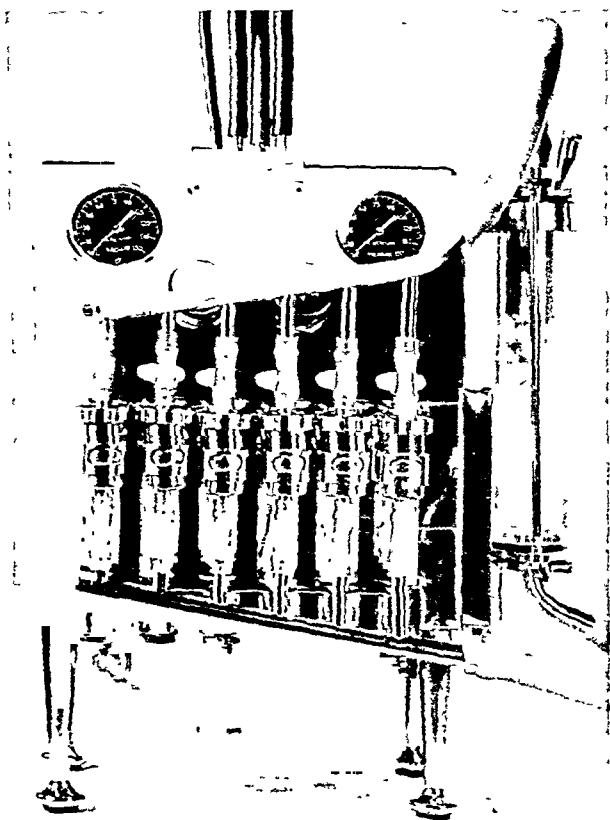


Fig. 5.—Photograph of the mechanical heart used.

Operation was carried out on Oct. 21, 1952. The mechanical heart and other apparatus had been assembled in the operating room before the patient arrived (Fig. 5). For a more detailed description of the mechanical heart used, the reader is referred to our earlier manuscript.⁵ A large cannula was placed in the right ankle vein. The patient was then given 5 mg. of heparin per kilogram of body weight. A total of 38.1 mg. of heparin was used, and from this amount 8 mg. was placed into the donor blood which

enlarged under direct vision. The long flaps of valve tissue protruding into the pulmonary artery were excised.

We have had a great deal of experience with the mechanical heart in experimental work. There seems little doubt but that either the right or left heart can be by-passed while the other side and the lungs continue to perform their functions. With a by-pass of the right heart in dogs, the blood may be taken from the right atrium, passed through the mechanical heart and back into the pulmonary circuit through the artery to the right lower lobe of the lung, the cannula pointing centrally. By this method, blood is supplied to the middle lobe, the right upper lobe, and the entire left lung. The right ventricle and pulmonary valve thereby may be completely by-passed. Other investigators^{3, 4} also have by-passed the right heart using similar methods in experimental animals. In the experimental work of this nature, we have found that with sufficient suction applied to the right atrial cannula the tricuspid valve apparently sealed itself and, although the right ventricle was opened, there was no bleeding or aspiration of air into the cannula. If there is a small amount of blood getting into the right ventricle, a light clamp may be placed across the pulmonary conus without interference with cardiac function. The pulmonary valve is, therefore, completely removed from the circulation. By this method, the coronary sinus blood, together with all the blood entering the atrium, is passed through the mechanical heart. If, on the other hand, the venae cavae are cannulated, there must be a separate plan for handling the coronary sinus blood.

The experimental work on dogs shows that there are right-sided hypotensive reflexes present which may be of extreme degree. These may be initiated by traction upon the pulmonary vessels.⁵ In operations upon the lung on human beings, it is not usual to see significant hypotension while traction is being applied to the vascular structures. There could exist, however, short periods of hypotension in such operations on human beings which would not be detected by the usual sphygmomanometer method. This hypotension is thought to be due to the Bainbridge reflex. The hypotension due to traction upon the vascular structures may or may not be a part of the same mechanism. It is our impression that many physiologic studies need to be made on this problem.

CASE REPORT

The patient who underwent this procedure was a 16-year-old white boy. His weight was 76.3 kg. He had been short of breath on slight exertion for many years. The boy was unusually large for his age; he was well developed with large muscular structures. There was no visible cyanosis or clubbing of the digits, and the general physical examination was entirely normal except for the cardiovascular examination. The heart was regular in rhythm. There was a loud harsh systolic murmur over the pulmonary valve area. This could be heard less distinctly over the rest of the thoracic wall. The blood pressure was 110/70 mm. Hg.

The red blood count was 4,950,000 per cubic millimeter. There was 14.5 Gm. of hemoglobin per 100 c.c. The white blood count was 6,200 per cubic millimeter with a normal differential count. Urinalysis showed a specific gravity of 1.022 with no evidence of albumin, sugar, or cellular elements being present. The Kahn test for syphilis was negative. The nonprotein nitrogen was 30.0 mg. per cent; the prothrombin was 100 per cent

of normal; the clotting time was 13 minutes. X ray examination of the thorax as well as fluoroscopy showed the right side of the heart, especially the right atrium, to be greatly enlarged. The main pulmonary arteries were hugely dilated. There were no visible pulsations of the pulmonary vessels seen at fluoroscopy.

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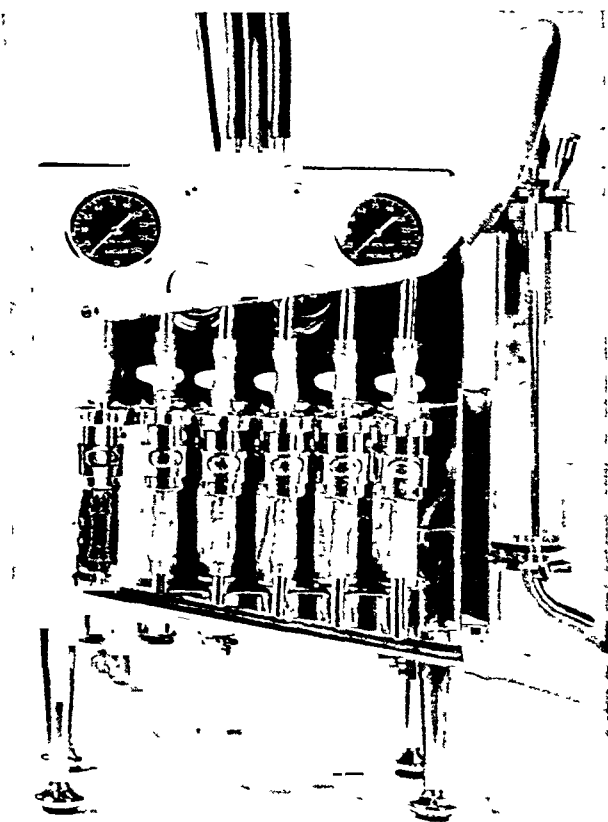


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The mechanical heart already had been assembled and filled with donor blood. The tubing leading to the mechanical heart and away from it were then connected to the canulae in the atrium and pulmonary artery, care being taken that no air bubbles got into the circuit. The mechanical heart then was slowly turned on until the entire right-sided circulation was diverted from the ventricle. The maximum flow through the mechanical heart was found to be $4\frac{1}{2}$ L. per minute. The heart showed no arrhythmias and there was no great fall in systemic blood pressure. After the action of the heart and the electrocardiogram had been observed for two or three minutes, there being no change, the main pulmonary artery was isolated from the ascending aorta. It was greatly dilated. A clamp was placed across the pulmonary artery just proximal to its bifurcation. A light noncrushing clamp was placed across the pulmonary conus thereby completely walling off the pulmonary valve from the circulation. The stenotic valve which protruded out into the base of the pulmonary artery could be palpated. A transverse incision was made at the base of the pulmonary artery and the pulmonary valve was well visualized (Fig. 7).



Fig. 7.—Photograph taken at operation showing exposed stenotic pulmonary valve in a living patient. A, Retracted edge of incised pulmonary artery. B, Stenotic pulmonary valve.

A valvuloplasty was carried out under direct vision. A bicuspid valve was constructed and the long flaps of excess were excised (Fig. 8, A and B). The incision in the pulmonary artery was then sutured with No. 0000 arterial silk. The clamps were removed and the mechanical heart was slowly shut off, allowing the right ventricle to resume its former function. After the right ventricle had resumed its function, there was a very

filled the mechanical heart and the remainder was given intravenously to the patient. Ten minutes after the heparin was given, the clotting time was taken and this test was repeated for the next four hours, during which time there was no evidence of clot formation. The right ulnar artery was exposed, and a No. 8 Courmand cardiac catheter was inserted and passed up to about the innominate artery. This was connected to a direct recording device so that a continuous arterial pressure could be recorded at all times. A continuous electrocardiogram was also recorded (Fig. 6).

Ether anesthesia was administered by Dr. A. B. Stearns. A transverse incision was made on the anterior thoracic wall, and both thoracic cavities were entered through the third intercostal spaces. The sternum was transected. After inserting a rib spreader on either side, a very wide exposure of the thoracic contents was obtained. Inspection and palpation of the heart showed a huge right atrium and right ventricle. There was a very vigorous systolic thrill over the base of the pulmonary artery.

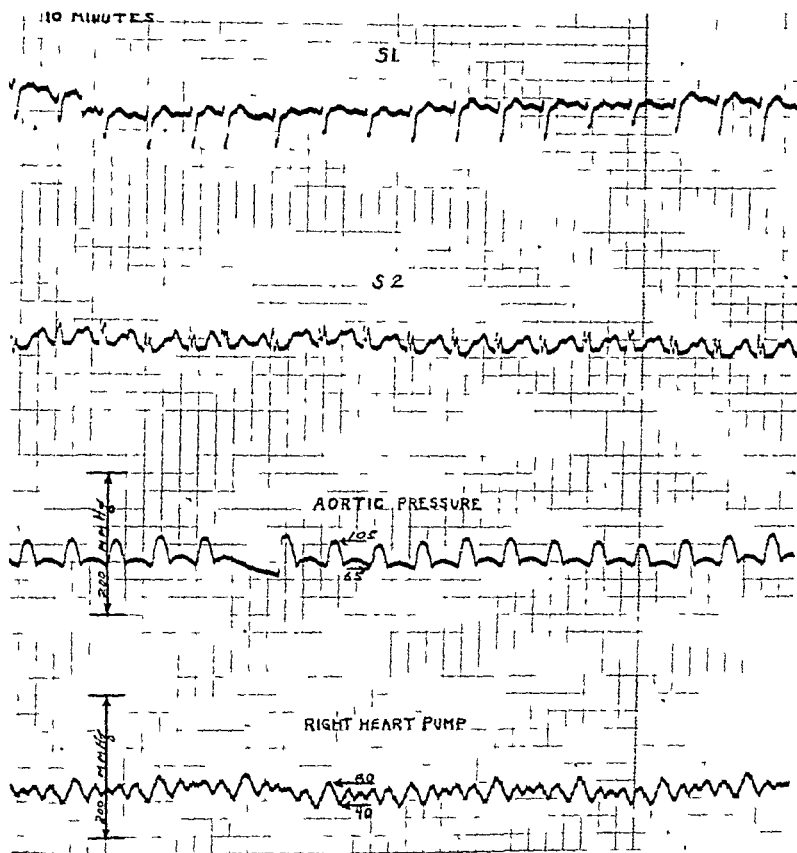


Fig. 6.—Record of electrocardiogram, arterial pressure, and the blood pressure as it leaves the mechanical heart during a complete by-pass of the right heart in a patient.

The interlobar fissure on the right side was separated, and the artery to the right lower lobe was isolated. An 8 mm. cannula was inserted into the artery and tied in place. The cannula was pointed centrally so that blood was supplied to the middle lobe, the right upper lobe, and the entire left lung. The pericardium was then opened on the right side, exposing a huge right atrium and atrial appendage. A 10 mm. cannula was inserted into the atrium through the appendage and sutured in place.

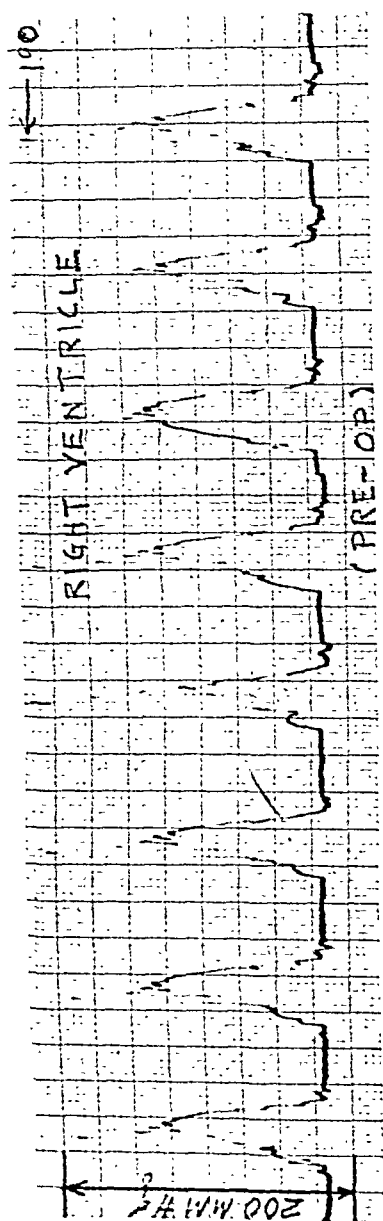


Fig. 9.—Preoperative right ventricle pressure in this patient.

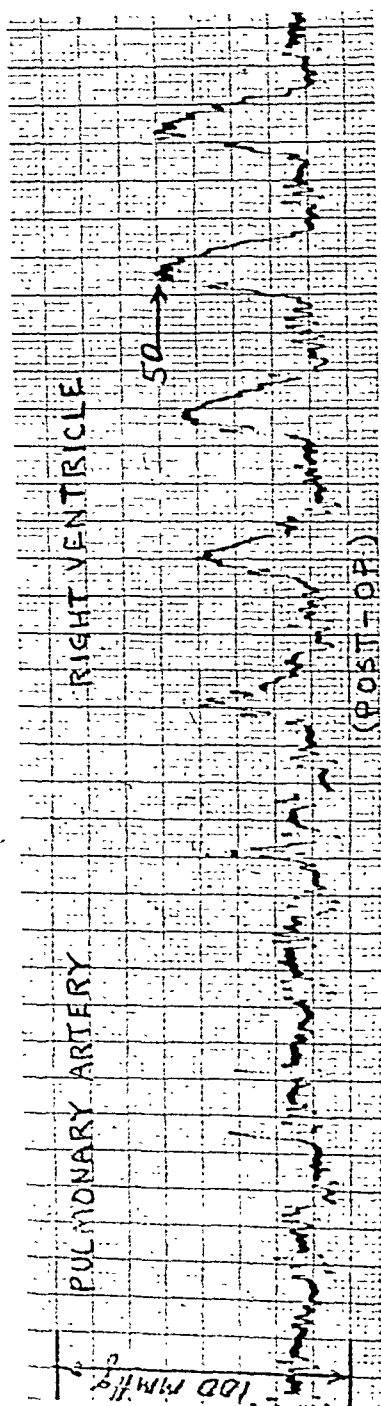


Fig. 10.—Right ventricle and pulmonary artery pressure six months after operation.

faint systolic thrill felt in the dilated pulmonary artery. This could be accounted for by the dilatation of the pulmonary artery. The mechanical heart was disconnected from the cannulae which were then removed. The incision in the pulmonary artery to the right lower lobe was sutured transversely, re-establishing its continuity. The atrial appendage was ligated at its base and excised. The incision in the chest wall was then sutured with interrupted silk sutures with drainage tubes placed in both thoracic cavities. The heart action remained good throughout the procedure, there being no arrhythmias. There was considerable blood loss during the removal of the cannulae which produced moderate hypotension. The patient received blood replacement throughout the entire procedure.

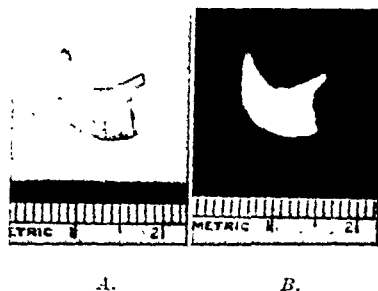


Fig. 8.—A and B, Flaps of excess pulmonary valve tissue excised.

Postoperatively the patient was in fair condition. There was some dyspnea, requiring oxygen therapy. The temperature remained elevated for approximately one week. The patient received intensive antibiotic therapy for three weeks. Blood-streaked sputum was raised for one week following the operation. X-ray examination of the thorax revealed bilateral lung disease which was interpreted as pulmonary edema. This completely cleared within two weeks. A low-pitched systolic murmur is still heard over the pulmonary valve area.

Extensive blood chemical examinations were made both before and after operation. No significant change could be detected other than those common to any major procedure of this magnitude.

The patient was discharged one month after the operation, having remained in the hospital longer than usual for purposes of observation. There has been marked clinical improvement, and the patient no longer complains of dyspnea. He has been working as a freight handler, although against advice.

The postoperative cardiac catheterization pressures are vastly different. Preoperatively the pressure in the right ventricle was 190 mm. Hg. Six months after the operation, the patient underwent cardiac catheterization, and the pressure in the right ventricle reached as high as 50 mm. Hg. The pulmonary artery pressure is now 22 mm. Hg (Figs. 9 and 10). Preoperatively it could not be obtained. The arterial oxygen saturation is now 97.2 volumes per cent, having risen from the preoperative level of 90 volumes per cent. It may be assumed that the lowering of the saturation was due to the low pulmonary artery pressure. The size of the heart has decreased as illustrated in Fig. 11, A and B. A photograph of the patient is shown in Fig. 12.

This is, to our knowledge, the first instance of a complete by-pass of the right heart in a patient. Obviously there must not be a defect of the cardiac septa with such a procedure. Dogliotti⁶ reported a successful partial by-pass of the right heart of a patient undergoing surgery for a mediastinal tumor. He reported the blood flow through his artificial mechanism as 1 L. per minute. Since his patient was an adult, the amount of blood diverted from the right side of the heart would be approximately one-third to one-fourth of the total right-sided circulation. Since our patient did well with this procedure, it is proof that a unilateral by-pass of the heart in patients can be done. We rec-

period, it was necessary that he be kept flat in a plaster cast. Approximately one week postoperatively, the patient became ambulatory and, as he was in the upright position, a very critical situation developed. He suddenly became extremely dyspneic and cyanotic. The attendants around him thought that he was dying. He collapsed and fell to the prone position, following which he revived and seemed essentially normal while in the prone position. The next day he was again made to sit up, and the same situation developed. He again collapsed and fell to the prone position, and was again revived. The following day he suddenly died. Post-mortem examination showed a huge embolus which had gotten into the right ventricle and would, in the upright position, totally obstruct the pulmonary valve. As the patient collapsed and fell flat, the embolus would drop down into the lower ventricle where the circulating blood could pass around it. If such a condition could be diagnosed in sufficient time, the embolus could be removed. These are mere examples of the application of a complete by-pass of the right heart, and probably many other conditions exist for the clinical application of this procedure.

SUMMARY

1. A successful complete by-pass of the right heart in a patient with congenital pulmonary stenosis is reported. The left heart and the lungs continued to perform their functions.
2. The main pulmonary artery was clamped off for twenty-five minutes while the pulmonary valve was exposed and enlarged under direct vision.
3. The blood flow through the mechanical heart was $4\frac{1}{2}$ L. per minute.
4. The patient is vastly improved.
5. To our knowledge, this is the first successful total by-pass of the right heart in a patient.

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DISCUSSION

DR. CONRAD R. LAM, Detroit.—Apparently this rather large operation was utilized to correct valvular pulmonic stenosis because it appeared that the Brock operation is not a good one, although it was so referred to in the abstract. I am not aware that Mr. Brock has reported any unfortunate recurrences with his patients in which original satisfactory operations were performed. Our own experience has been with fourteen patients with valvular pulmonary stenosis, two of which were complicated. The twelve who had uncomplicated conditions are all well, with excellent postoperative catheter

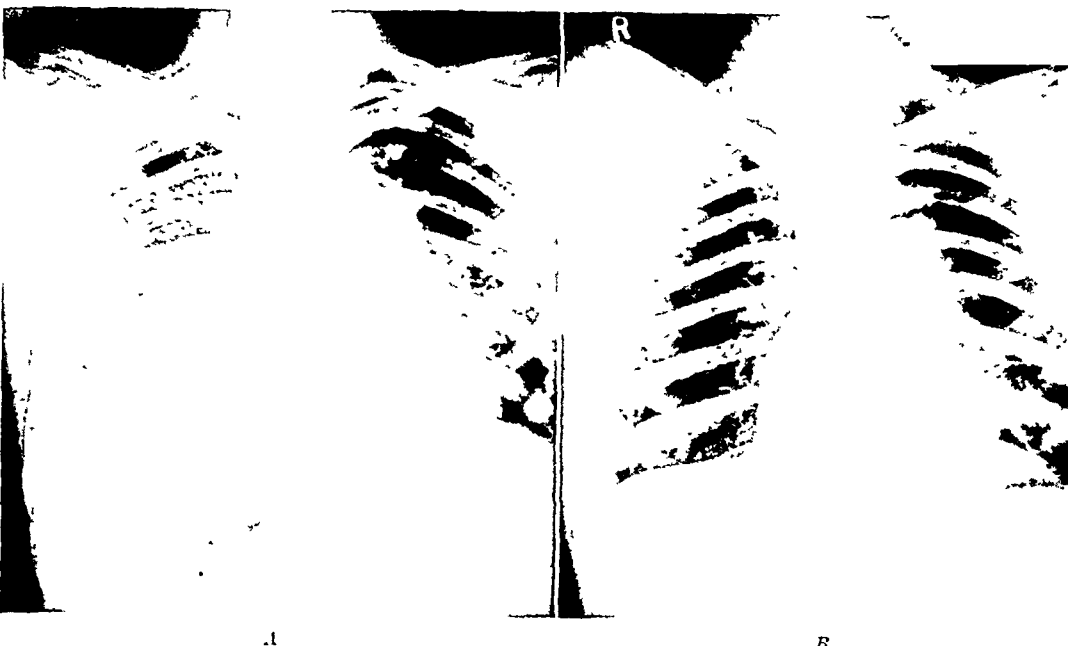


Fig 11 —A, Size of heart at operation; B, size of heart six months after operation.



Fig 12.—Photograph of the patient one month after operation

ognize the fact that not many patients with congenital pulmonary stenosis could undergo this procedure, since many of them have septal defects as well.

There are not a great variety of diseases of the right heart in which the right-sided by-pass could be used. Pulmonary stenosis without other defects is one example. Diseases of the tricuspid valve may be another example. There are also rare examples of large emboli lodging in the right side of the heart producing serious warnings before a fatal issue.

Such a condition is briefly illustrated by the following experience. A young adult underwent surgery on the lower spine. During the postoperative

we felt it might be feasible because the regurgitant pressure would presumably amount to approximately only 8 mm Hg, that is, the diastolic pressure of the pulmonary artery. For that reason we have recently given this a clinical trial in three patients by the use of general hypothermia.

(Slide.) It is necessary to have a bathtub full of ice water to put the patient in, with a constant temperature recording machine. Note the anesthetist's respiration device; hyperventilation throughout the procedure is very important.

(Slide.) The operative procedure is essentially simple. One puts tapes around the venae cavae and ties the azygos vein. Pull up on the tapes and after about thirty to forty five seconds the heart will be quite empty. It is now possible to make an incision in the pulmonary artery directly over the valve, and in the dry field there it is possible to grasp the valve and excise it. A noncrushing clamp is then applied to the incision in the pulmonary artery after flooding it with saline solution. Blood flow may now be resumed while the artery is sutured. We actually occluded the circulation in these three patients, one for seven and one half minutes, one for three and one half minutes, and one for three minutes and five seconds.

(Slide.) This shows the valve resected in one patient, and includes the original small lumen. Here is the valve with the lumen.

In these three children, all had essentially a noneventful postoperative course. The period of observation has been short. They had immediate dramatic improvement in exercise tolerance, but I would not like anyone to believe that at this time we recommend this procedure for general adoption. Certainly we must wait for a time to evaluate the effect of total valvular excision and the importance of pulmonary regurgitation in the human patient.

DR. GEORGE H. HUMPHREYS, New York—I am surprised to hear of these very radical operations for an anomaly which can be corrected as directly and simply as it can be by the Brock procedure. In an experience of about thirty cases, using the conventional Brock knife, we have had only one death, and that was due to a technical error. I think that the degree of right ventricular hypertension which persists after the procedure is not very well known, and probably some of those patients in whom it has been documented have had a high right ventricular pressure ever since the procedure; in other words, the procedure has not been an adequate one to begin with.

We have been able to catheterize a number of these patients on the operating table and obtain right ventricular pressures immediately after the Brock procedure. In some cases when we felt that technically we had done a good job, we found that the pressure was still high, and we were able to go back and stretch the valve again and obtain a normal pressure. I think that perhaps some of the late so called poor results are due to an inadequate operation in the first place. I think another cause is often overlooked, that it is a very small ventricular septal defect. Several of these have been encountered that were not detected by catheterization before operation. In these patients the right ventricular pressure balances the left, and there is little or no shunt in a high small ventricular septal defect, that is, no arterial blood will be detected in the right outflow tract on catheterization. However, after operation, arterialization can be detected in the outflow tract, and that means that a small ventricular septal defect is present and that the high right ventricular pressure is due to this and not due to recurrent stenosis.

DR. DODRILL (Closing)—I realize that a right sided bypass will not be applicable to many patients with congenital pulmonary stenosis because the vast majority do have septal defects of one sort or another. The point that this illustrates is that a right sided bypass seems to be a practical procedure that may be applied in the future to other diseases, aside from pulmonary stenosis. I think such drastic procedures as those that are in a development stage will of necessity carry a higher mortality rate than those procedures which have already been worked out. When we think back a few years to recollect the mortality rate in simple lung resections, then a mortality rate of less than 50 per cent, which we have had in our over all results, I think is not too discouraging, particularly in view of the fact that most of the patients have been far advanced, and may possibly have carried a similar mortality with the Brock procedure.

studies. One of the two patients with complicated cases was an infant aged 3 months. The Brock valvulotomy was performed about ten minutes after the beginning of the operation. The child did not survive, and the autopsy showed that the aortic valve was involved in a similar process. The second patient who did not survive had a long infundibular stenosis in addition to the valvular stenosis, and there was difficulty in inserting the Brock valvulotome. Although the valve was opened moderately, for some reason death occurred several hours after the procedure.

The last operation of this type was on a 48-year-old woman. The total operating time, from the beginning until the incision was closed, was one hour and three minutes.

I should like to have Dr. Dodrill tell us if this is the only case he has had. One would suspect that a rather high initial mortality would ensue.

DR. HARRIS B. SHUMACKER, JR., Indianapolis.—Dr. Dodrill mentioned the need for more postoperative catheterization studies following pulmonary valvulotomy performed according to the method of Mr. Brock. Up to the present time there is very scant information of this sort in the literature. Although I have very little to add I thought it might be of some interest.

Dr. Paul Lurie and I have been interested in functional studies on patients with pulmonic valvular stenosis without ventricular septal defect. Thus far only seven patients have been subjected to catheterization before, and some time after, operation. All seven of these patients had mild or moderate symptoms. All have done very well clinically and have been relieved of the symptoms present before operation. Studies of right ventricular pressure after operation have been somewhat disappointing. In five patients there was a slight fall in right ventricular pressure and in two a marked fall, but in none was there a return to an absolutely normal level. The calculated valve area was the same after operation as before in two patients and was increased in the other five, but in none was it calculated to be more than three times as large as before operation. We realize, of course, the limitations of accuracy in the estimation of valve area.

Studies of arterial oxygen saturation, breathing room air and pure oxygen, have, on the other hand, been more encouraging. Of four patients who had a definite veno-arterial shunt before surgery, the evidence of shunt has completely disappeared in two and has been reduced to a borderline degree in the other two. Evidence of a borderline veno-arterial shunt in one patient has remained unchanged since operation. In another patient with an intermittent veno-arterial shunt before operation, no shunt is apparent afterward.

Possibly of greater significance than the other results of catheterization is the observation that one patient with a very high preoperative right ventricular pressure not reduced significantly by operation has been shown postoperatively to have a normal increase in cardiac output with exercise or, to put it more precisely, a normal increase in pulmonary artery flow. Quite in contrast, one patient with very mild pulmonary valvular stenosis and with a right ventricular pressure of only 40/0 demonstrates no rise whatsoever in pulmonary artery flow with exercise. She has not been treated surgically. It is possible that exercise effectively increases the mobility of the surgically made bicuspid valves and that the valve area is actually increased under stress over what it is at rest. It is planned to continue such studies.

We cannot help wonder whether the poor correlation between certain laboratory observations and the clinical course of the patients is not due to the fact that, up to the present, we have not focused our attention upon those particular laboratory studies which would reveal an actual improvement comparable to that which has been observed in the clinical course of all our patients, regardless of whether their symptoms before operation were mild, moderate, or marked.

DR. HENRY SWAN, II, Denver.—We too have been much concerned about the tendency of the right ventricular pressures to stay well above normal limits following the Brock procedure, in spite of the fact that there is marked clinical improvement in the patient. For that reason we have considered the possibility of actually excising the valve, realizing of course that this would cause regurgitation. Dr. Hufnagel has shown that one can excise the pulmonary valve in the normal dog. In addition, on theoretical grounds

introduced plastic discs on either side of atrial septal defects and then mechanically secured them to each other so that a rim of septal tissue was grasped by the discs. These plastic prostheses were rapidly covered with endothelium and were apparently well tolerated by experimental animals. In order to use this method, the rim of septal tissue must be complete, otherwise the button will not remain in position.⁵

Gross^{2, 3} has closed interatrial septal defects in seven patients, operating through an open rubber well sutured to the margins of a wound in the right atrium. Blood rises a few centimeters in the well to a height equal to the atrial pressure. By digital palpation through the well, Huftnagel buttons were placed across the defect in three patients, a sheet of nylon or polyethylene was sutured to the margins of the defect in three other patients, and in one patient two defects were closed by simple suture. Because of incomplete septal rims the Huftnagel buttons became dislodged and the three patients subsequently died. One death occurred in the three patients whose defects were closed by nylon or polyethylene sheets. The three surviving patients are all improved but catheterization studies reveal a persistent but greatly diminished left-to-right shunt at the atrial level.

In the methods just referred to the surgeon has the serious handicap of being unable to see the extent of the defect or the operative field in which he is working. A clear field of vision can be obtained only by preventing the blood in the venae cavae from entering the right atrium. Without an extracorporeal blood circuit to maintain cardiorespiratory functions, the venae cavae can be safely occluded for only three or possibly five minutes. Lowering the body temperature to reduce metabolism has recently been proposed and employed to increase the duration of safe caval occlusion.

Martin and Essex¹³ and Swan¹⁹ have experimentally created interatrial septal defects under direct vision during exclusion of the heart from the circulation by caval occlusion at normal body temperatures. By reducing the body temperature, Bigelow³ has shown that the period of caval occlusion may be markedly prolonged. In a recent article,⁴ Bigelow reports that with hypothermia in monkeys, the heart may be excluded from the circulation for as long as twenty-four minutes with survival. This method has been used successfully in human beings.^{1, 12} Without extracorporeal maintenance of the cardiorespiratory functions, caval occlusion, even with hypothermia, provides only a brief safe interval of time for open cardiomy. Exceeding this brief time interval will result in cerebral damage or death.

In our opinion a safer method of obtaining a bloodless heart consists in the maintenance of the cardiorespiratory functions of the subject by a pump-oxygenator apparatus while the venae cavae are occluded. This gives adequate time for precise surgical procedures within the open heart. Both venae cavae have been occluded in animals for as long as one hour and forty minutes with prolonged survival of the animal in a healthy condition.¹⁴ Dennis and his co-workers⁶ attempted the repair of an interatrial septal defect in a human being under direct vision, using an extracorporeal circuit embodying an oxygenator. The defect was closed but the patient died.

THE PRODUCTION AND REPAIR OF INTERATRIAL SEPTAL DEFECTS UNDER DIRECT VISION WITH THE ASSISTANCE OF AN EXTRACORPOREAL PUMP-OXYGENATOR CIRCUIT

BERNARD J. MILLER, M.D. (BY INVITATION), JOHN H. GIBBON, JR., M.D.,
VICTOR F. GRECO, M.D. (BY INVITATION), BURGESS A. SMITH, M.D.
(BY INVITATION), C. HAROLD COHN, M.D. (BY INVITATION), AND
FRANK F. ALLBRITTEN, JR., M.D.
PHILADELPHIA, PA.

A NUMBER of methods have been proposed and employed for the closure of interatrial septal defects without diverting the circulation from the heart. In none of these methods can the surgeon see the margins of the septal defect.

Cohn⁵ demonstrated that experimentally produced defects in the interatrial septum could be closed by suturing the wall of the right atrium to the margins of the defect. The stalk resulting from the invagination of the right atrial wall was then divided and the defect in the atrial wall sutured. Bailey² has recently modified this procedure in patients by not dividing the invaginated stalk. He also inserted a finger into the right atrium during the procedure so that the margins of the defect could be palpated during the placement of sutures. With large defects, unless the atrium is greatly dilated, there is some danger of obstructing the return from the venae cavae by this method. Shumacker¹⁸ has avoided much of the reduction in size of the atrial chamber by the use of a pouch of pericardium. A small sac of pericardium is constructed and sutured to the margins of an incised wound in the atrium. The sac is then invaginated into the atrial chamber and sutured to the margins of the atrial defect.

Swan and his associates¹⁹ have closed experimentally produced interatrial septal defects in animals by invaginating both auricular appendages and opposing the tips through the septal defect by mattress suture through two plastic buttons. A modification of this method has recently been applied to the closure of interatrial septal defects in human patients.²⁰ Postoperative studies in two patients showed incomplete closure of the defect.

Murray,¹⁰ in four human beings, attempted to close defects in either the interatrial or interventricular septum by passing mattress sutures of fascia lata or silk across the defect in the plane of the septum. When these sutures were tied, the resulting compression of the septum apparently reduced the size of the defects. No subsequent reports have appeared and it seems unlikely that complete closure of septal defects can be accomplished by this method.

Large experimentally produced defects in the interatrial septum have been successfully occluded by means of a plastic prosthesis. Hufnagel and Gillespie¹⁰

From the Department of Surgical Research of the Jefferson Medical College.

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Any method which exposes the left side of the heart to atmospheric air (either a left cardiectomy, or a right cardiectomy in the presence of a septal defect) carries with it the danger of air embolism in the systemic arteries. Martin and Essex¹³ and Swan¹⁹ observed air embolism in the coronary arteries during the production of interatrial septal defects. The hazard of air embolism in the systemic arteries during the production or repair of interatrial septal defects in the opened heart still exists in hypothermic states. Lewis and Taufic¹² filled the left atrium with physiologic saline solution while the aorta and coronary arteries were clamped during closure of an interatrial septal defect in a human being. The clamp was released after the wound in the atrium had been sutured.

This method of avoiding air embolism by attempting to keep the left cardiac chambers full of fluid is not uniformly successful. Senning¹⁷ has demonstrated in dogs that air embolism of the systemic arteries can be avoided by inducing ventricular fibrillation during repair of atrial septal defects under direct vision employing an extracorporeal blood circuit. The pumping action of the heart is arrested during ventricular fibrillation and air cannot be pumped into the aorta. After the atrial wound had been sutured, normal rhythm could be re-established by a defibrillating electric shock.

The following report demonstrates that in animals interatrial septal defects can be successfully created and repaired under direct vision with an open cardiectomy while the cardiorespiratory functions are maintained by a mechanical heart and lung apparatus during the period of caval occlusion. In addition, the danger of air embolism can be avoided by what appears to be a safe and practical method.

APPARATUS

The pump-oxygenator used in these experiments is basically the same as that previously reported,¹² but the method of withdrawing blood from the venae cavae has been modified. Previously the roller type pumps were connected directly to the cannulae in the venae cavae. At the beginning of each pumping cycle when the roller began to compress the rubber tubing, there was a momentary positive pressure in the cavae. This was immediately followed by negative pressure as the roller moved onward compressing the tubing through an arc of 180 degrees. During the negative pressure phase of the pump cycle, the venae cavae frequently collapsed at the orifice of the cannula. Obviously the peak negative pressure of a fluctuating pressure cycle will be higher than a uniform negative pressure producing the same flow rate. Thus a lower steady negative pressure should produce the same rate of blood flow with less fluttering and intermittent occlusion of the cavae. By interposing between the cannula and the pump a vacuum chamber in which the blood collects, the pulsations produced by the pump have been eliminated.^{7, 11}

The modified extracorporeal circuit is illustrated diagrammatically in Fig. 1. The blood from both venae cavae is carried through a Tygon tube to the collecting chamber (A). A slight negative pressure is maintained within this chamber, which is placed at approximately the same level as the venae cavae. As blood from the cavae enters the collecting chamber, the level of the blood rises, thus

automatically energizing the pump (*E*). The pump (*E*) automatically maintains a constant level of blood in the negative pressure collecting chamber (*A*) by means of the variable capacitor previously described.¹³ With the smooth constant suction obtained by the interposition of chamber (*A*) between the roller pump and the vena cava, individual control of the flow rate from each cava is no longer necessary.¹¹ The amount of negative pressure needed to empty the cavae can be easily and quickly regulated. The negative pressure required is rarely greater than 10 mm. mercury.

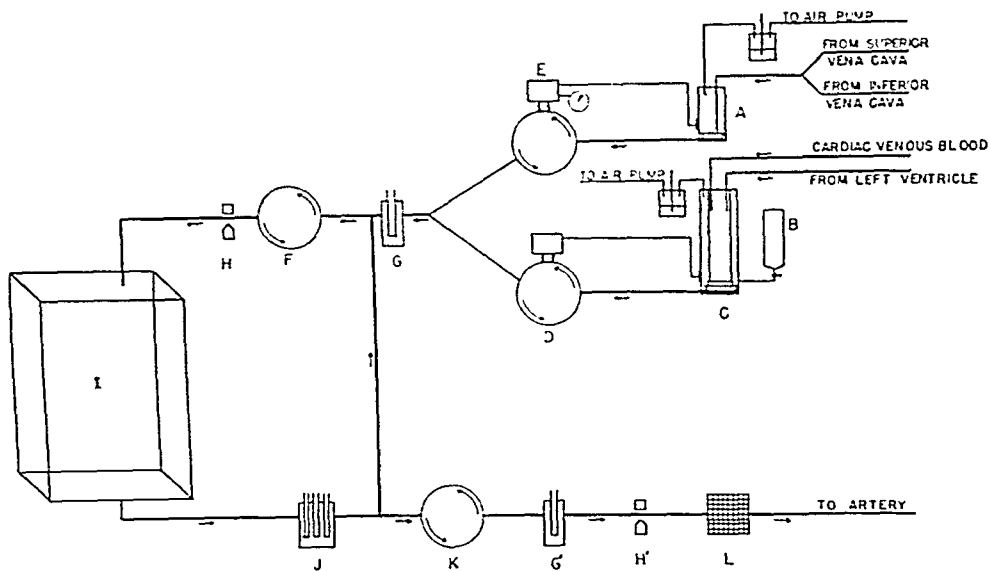


Fig. 1.—Extracorporeal pump-oxygenator circuit. *A*, Systemic venous blood collecting chamber. *B*, Blood burette. *C*, Collecting chamber for blood from open right atrium and blood from vent in left ventricle. *D*, Automatically controlled pumps for emptying cardiac venous blood collecting chamber. *E*, Pump for emptying venous systemic blood collecting chamber. *F*, Oxygenator pump. *G*, Thermocouple for venous blood temperature. *G'*, Thermocouple for arterial blood temperature. *H*, High-pressure sensing device. *H'*, High-pressure sensing device. *I*, Screen oxygenator. *J*, pH electrode holder. *K*, Automatically controlled arterial pump. *L*, Filter.

The cardiac venous blood entering the right atrium must be continuously removed from the operative field in order to provide exposure of the interatrial septum. The blood and air aspirated from the right atrium are conducted through a Tygon tube to the inner cylinder of collecting chamber (*C*) and spread in a thin film.¹⁴ The bubbles of air disperse from the blood film as it descends by gravity to the pool at the bottom of the chamber.

As stated, when an open right atrial cardiomy is performed in the presence of an interatrial septal defect, the left atrium is exposed to atmospheric air. During diastole, air and blood pass through the mitral valve into the left ventricle. During systole the mitral valve closes, and both air and blood will be forced into the aorta with resultant air embolism of the coronary and other systemic arteries. The simplest and safest method of avoiding such air embolism is to provide a low-pressure vent for the left ventricle. With systole, the contents of the left ventricle will then be expelled through the vent instead of

being forced into the aorta. A Tygon tube 5 mm. in diameter is inserted into the left ventricular chamber by means of a stab wound in the apex. This tube conducts blood and air from the left ventricle to the collecting chamber (*C*). The negative pressure in chamber (*C*) is maintained at approximately 30 mm. Hg.

In the following experiments the blood collecting in the bottom of chamber (*C*) was returned to the venous side of the extracorporeal blood circuit by means of a manually controlled pump. As illustrated in Fig. 1, a variable capacitor, similar to that operating pump (*E*), is being constructed which will automatically energize the pump (*D*) and maintain a constant blood level in the chamber (*C*). This has been shown to operate satisfactorily.¹⁴

The oxygenator pump (*F*) draws blood from the bottom of the oxygenator case as well as from the two venous pumps (*D*) and (*E*). The flow through this pump is fixed at a rate which is greater than the sum of the maximum flow rates through the pumps (*D*) and (*E*). The oxygenator pump maintains a constant flow rate over the screens and so insures constancy of the volume of blood held on the screens. This avoids any change in the volume of blood in the subject's blood vessels during the course of the perfusion.

The high-pressure sensing device (*H*) becomes operative in the event of occlusions of the slits in the distributor chamber of the oxygenator and stops all pumps in the extracorporeal circuit. This event has never occurred in eighteen months' continuous use of the apparatus.

The oxygenator (*I*) consists of a series of vertically suspended stainless steel screens.¹⁵ Blood enters the distributor chamber at the top of the oxygenator and then descends by gravity over the screens and accumulates in a small pool at the bottom of the oxygenator case. An electronic device similar to that controlling the pumps (*D*) and (*E*) operates the arterial pump (*K*) so as to maintain a constant level of blood in the bottom of the oxygenator case at all rates of blood flow.

Before entering the subject, the oxygenated blood passes through the electrode assembly (*J*) where the pH is continuously measured and recorded by a self-balancing potentiometer. The pH is automatically maintained at the level desired by the intermittent addition of carbon dioxide to the oxygen flowing through the oxygenator. Thermocouples placed within the chamber (*G*) and (*G'*) measure the temperature of the venous and arterial blood. The temperatures are recorded on a self-balancing potentiometer on the front panel of the main cabinet. The high-pressure sensing device (*H'*) automatically stops the venous and arterial pumps should high pressure develop as a result of an obstruction in the tube returning blood to the subject. The pumps remain inoperative until the obstruction has been relieved.

PREPARATION OF THE APPARATUS

The apparatus was prepared as has been previously reported.¹⁵ All components of the blood circuit were completely disassembled and mechanically cleaned with detergent solution. Following reassembly of the apparatus, the blood circuit the oxygenator case was filled with a 1:1,000 solution of

aqueous benzalkonium chloride. After one hour the benzalkonium chloride solution was removed and the blood circuit filled with sterile physiologic saline solution. The saline solution was then drained and the system washed with six separate fifteen-minute rinses of 1,500 ml. of sterile physiologic saline solution.

The tubing of the extracorporeal circuit was then filled with heparinized blood obtained from donor animals. These animals received an intravenous injection of 3 mg. per kilogram of body weight of heparin before exsanguination. Usually 2,000 ml. of heparinized blood was obtained from donor animals. The extracorporeal circuit volume was 1,200 ml. when the small oxygenator was used. An additional 600 ml. of heparinized blood was required when the large oxygenator¹⁴ was used. The blood remaining after the extracorporeal circuit was filled was used to replace blood lost during the operation and also blood withdrawn for gas analysis. An additional 1,000 ml. of citrated blood was obtained from a donor animal. This was used to replace blood lost by sero-sanguineous effusion into the pleural cavities postoperatively.

The donor blood was circulated through the apparatus from a small flask in a constant temperature water bath. The blood film was established on the screens of the oxygenator a short time before the subject was connected to the extracorporeal circuit. The oxygenator pump (*P'*) was set at a flow rate of 1,800 ml. per minute when the small oxygenator was used and at a rate of 3,500 ml. per minute when the large oxygenator¹⁴ was in the circuit.

OPERATIVE TECHNIQUE

The dog was given an intramuscular injection of 3 mg. per kilogram of body weight of morphine sulfate approximately forty-five minutes before operation. Anesthesia was induced and maintained by intravenous 2.5 per cent Pentothal Sodium solution. An endotracheal tube with an inflatable cuff was placed within the trachea and connected to an electrically controlled positive and negative pressure respirator capable of producing apnea by overventilation.

Both femoral arteries were exposed. With the animal lying on its left side, the right pleural cavity was entered through the bed of the fifth rib. The superior and inferior venae cavae and the vena azygos major were exposed and braided silk ligatures placed beneath them. Heparin was then injected intravenously in the amount of 3 mg. per kilogram of body weight. The arterial and venous pumps were stopped, but the oxygenator pump maintained the blood flow over the screens of the oxygenator. Clamps were applied to the tubes leading to the extracorporeal circuit. The arterial and venous cannulae were then connected to these tubes. Generally one, but occasionally both, femoral arteries were cannulated centrally for the return of arterial blood from the apparatus. Either the remaining femoral artery or the left brachial artery was cannulated for direct measurement of blood pressure.

One venous cannula was inserted in a cephalic direction in the superior vena cava through an opening in the azygos vein. A pedicled pericardial graft was then cut (Fig. 2, A). The attached base of the graft was cephalad. The second venous cannula was then inserted in the inferior vena cava through an opening in the tip of the right auricular appendage.

The clamps were removed from the tubes leading to the extracorporeal circuit, thus diverting a part of the systemic venous return to the heart through the apparatus. The arterial pump automatically returned, at the same rate, arterial blood to the femoral artery from the extracorporeal circuit. The ligatures previously placed around the venae cavae were tied over the cannulae completely diverting the systemic venous blood flow to the extracorporeal circuit (Fig. 2, *B*). Ventilation of the lungs by the respirator was then discontinued as it was no longer necessary, and the absence of respiratory movement made the subsequent operative procedures easier.

In the first group of seventeen dogs, the right atrium was widely exposed by an incision extending from the right auricular appendage to the inferior vena cava parallel to the coronary sinus. The operative field was kept relatively bloodless by aspirating the cardiac venous blood. A large portion of the interatrial septum above and posterior to the coronary sinus was excised under direct vision. The defect was roughly circular. The extent of the opening was measured by calipers in two axes.

After creation of the defect most of the cardiac venous blood flowed into the left atrium by gravity. This reduced or eliminated the need for aspirating cardiac venous blood from the operative field. Physiologic saline solution was continuously injected into the left atrium in an attempt to displace air from the left atrium and so prevent fatal air embolism of the coronary arteries.

The previously fashioned pericardial graft was then placed over the defect and secured to the cephalad margin of the opening by two interrupted 00000 Deknatel silk sutures placed on each side of the graft (Fig. 2, *C*). The free inferior edge of the graft was easily manipulated by two previously placed sutures. The free extremity of the graft was then drawn upward and cephalically, and the cephalad margin of the defect sutured to the under surface of graft with a continuous suture. The graft was then replaced over the defect and two interrupted sutures were placed, one on each side of the graft, fixing it to the caudad margin of the defect. The graft was then fixed to the margins of the defect by three continuous sutures connecting the previously placed interrupted sutures (Fig. 2, *D*). In the first six experiments the pedicle was divided close to the cephalic suture line after the graft had been sutured to the margins of the septal defect. An attempt was then made to aspirate air trapped beneath the graft in the left atrium by means of a needle inserted through the suture line.

The incised wound in the wall of the right atrium was closed by a continuous suture. Aspiration of the cardiac venous blood was discontinued before complete closure so that the right atrium would fill with blood. Small pledgets of Gelfoam saturated with thrombin solution were sutured over the atrial wound. The ligatures about the venae cavae were divided thus returning a part of the total blood flow to the animal's heart and lungs. The lungs were insufflated with the respirator. The tubes leading to the extracorporeal circuit were clamped. The venous cannulae were removed and the azygos vein and right auricular appendage ligated. The arterial cannula was removed and the femoral artery ligated.

The thoracic wound was sutured in layers. The pleural cavity was drained by two catheters as long as serosanguineous fluid could be obtained, usually four hours. A dilute solution of protamine sulfate, 0.1 to 0.05 per cent, was slowly

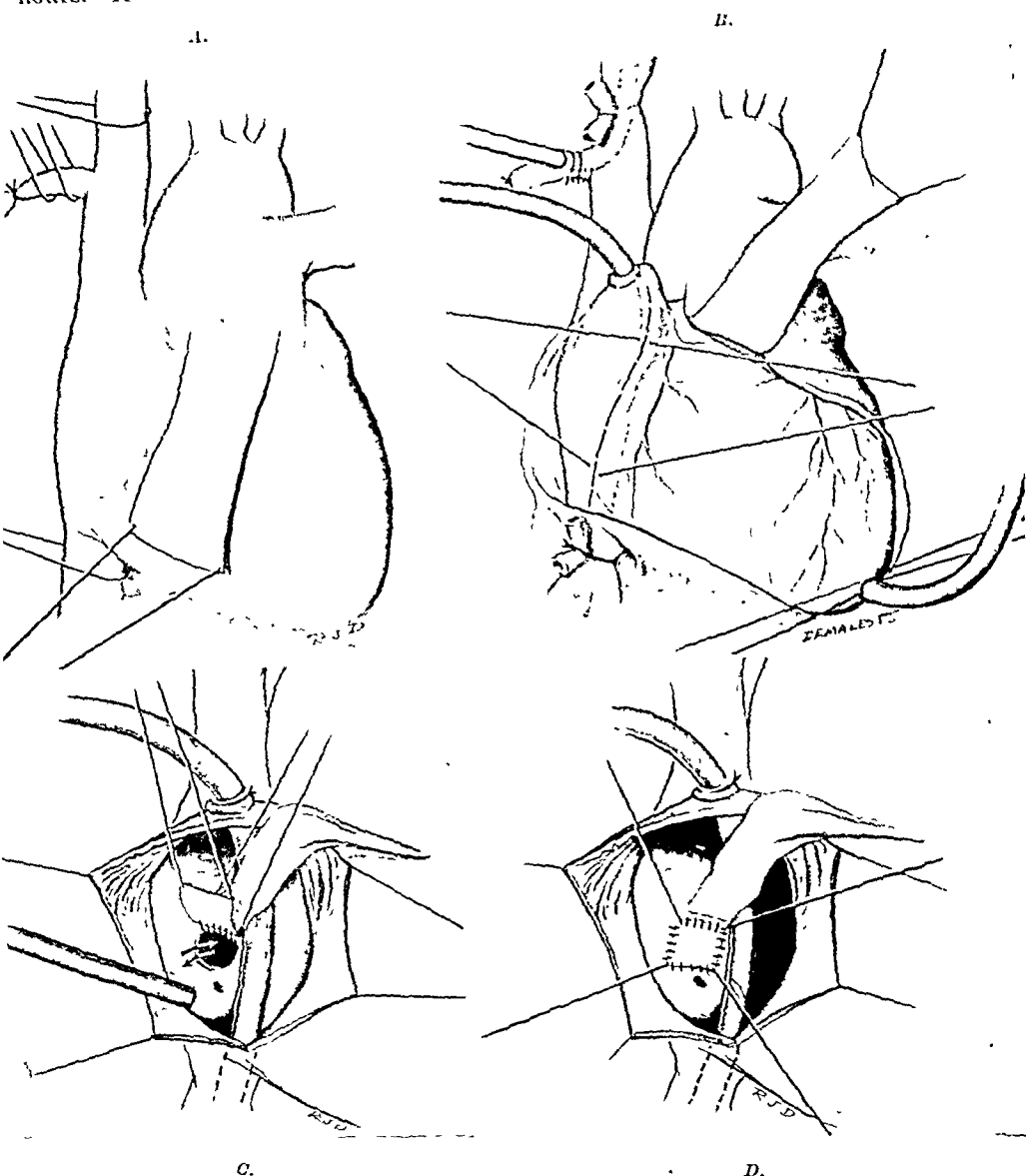


Fig. 2.—Method for closure of interatrial septal defects under direct vision with the assistance of an extracorporeal pump-oxygenator. *A*, Placement of ligatures around the venae cavae and azygos vein. Making the pericardial graft. *B*, The systemic venous return to the heart has been diverted by means of the cannulae placed within the venae cavae. The proposed line of incision in the right atrial wall is shown and the vent for the left ventricle has been established. *C*, The interatrial septum has been widely exposed and the sutures approximating the graft to the upper margin of the defect are shown. *D*, The graft has been completely sutured to the interatrial septal defect. The proposed line of division of the pedicle is shown.

TABLE I. PRODUCTION AND REPAIR OF INTRATHORACIC SEPTAL DEFECTS WITHOUT A VENT IN LEFT VENTRICLE

EXP. NO.	DATE	WT. OF DOG KG.	TIME		TIME HEART OPEN MIN.	SIZE OF DEFECT CM.	BLOOD DETERMINATIONS DURING LATTER PART OF CAVAL OCCLUSION						INTERVAL BEFORE SACRIFICED (S) OR DEATH (D) DAYS	REMARKS	
			VENAE CAVAE OCCLUDED MIN.	VENAE CAVAE OPEN MIN.			OXYGEN SATURATION		ARTERIAL BLOOD PH	HEMATO-CRIT PER CENT	HEMOGLOBIN IN PLASMA MG. HB/100 ML.				
							VENOUS BLOOD PER CENT	ARTERIAL BLOOD PER CENT							
1952															
0-497	Oct. 1	10	55		44		64	104	7.43	32	194	S-92	Pedicle graft		
0-498	Oct. 3	11	60		42	1.5	42	75	7.33	30	174	S-90	Pedicle graft		
0-499	Oct. 6	10	32		27	1.2 x 0.9	70	105	7.37	33	51	D	Died 4½ hr. from P.O. hemorrhage		
0-501	Oct. 10	11	41		36	1.6 x 1.0	62	97	7.38	38	74	S-116	Pedicle graft		
0-502	Oct. 14	11	57		50	1.5 x 1.2	60	99	7.30	43	49	S-157	Pedicle graft		
0-503	Oct. 16	11	43		32	1.5 x 1.4	46	98	7.35	40	95	D	Died during procedure from air embolism		
0-505	Oct. 24	12	37		33	1.9 x 1.5	59	98	----	38	216	S-147	Died during procedure from air embolism		
0-506	Oct. 28	12	70		22	-----	44	72	7.38	43	118	D	Died during procedure from air embolism		
0-507	Oct. 30	11	36		29	1.5 x 1.2	53	81	----	37	51	S-141			
0-508	Nov. 3	10	37		34		63	95	7.52	28	60	S-63			
0-520	Dec. 17	11	33		30	2 x 2	47	100	7.42	34	40	S-14			
0-521	Dec. 19	10	44		41	-----	41	95	7.37		89	D	Died in 24 hr. from overdose M.S.		
0-522	Dec. 22	11	43		41	-----	62	104	7.35	32	54	S-22	Died during procedure from air embolism		
0-523	Dec. 29	13	31		35	2 x 2	62	102	7.42	38	96	D			
1953															
0-524	Jan. 6	12	39		35	2	61	103	7.47	34	87	S-7	Air in cor. circuit		
0-526	Jan. 16	13	47		43	-----	70	103	7.30	43	65	D	Died in 10 hr. from P.O. hemorrhage		
0-527	Jan. 16	13	40		41	1.5 x 2	64	103	7.35	38	65	S-17	Air in coronary circulation		
Average			11	44	36		57	96	7.38	36	93				

injected intravenously until the coagulation time of the blood had approached a normal value. The animals received 300,000 units of procaine penicillin and 0.25 Gm. of streptomycin intramuscularly following the operation. Antibiotic therapy was continued for five to ten days postoperatively. All wounds healed per primam.

In the next group of seven dogs, a vent was established in the left ventricle to permit removal of air and blood during the production and repair of the interatrial septal defect. In two dogs a plastic cannula was inserted through the left ventricular wall in the angle between the circumflex and anterior descending branches of the left coronary artery. Blood and air escaped from this vent during the time the left atrium was open to the atmosphere. The blood accumulating in the pleural cavity from this vent was aspirated and returned to the extracorporeal circuit. This type of vent proved to be unsatisfactory and in the remaining five dogs a stab wound was made in the apex of the left ventricle and a small bore Tygon tube inserted into the chamber for a distance of approximately 3 cm. The tube was inserted into the left ventricle before the right atrium was opened, but after the venae cavae had been tied over the cannulae. The cardiac venous blood passing through the pulmonary circulation was thus removed from the left ventricle and diverted to the extracorporeal circuit. Once the vent had been established in the left ventricle, the right atrium could be opened and the interatrial defect created and repaired without danger of air embolism in the systemic arteries. While the communication between the two atria existed, bubbles of air could be seen passing through the Tygon tube leading from the left ventricle. After repairing the septal defect with the pericardial grafts, the right atrium was closed as described above. The ligature around the superior vena cava was then divided and the tube connecting the cannula in the superior vena cava to the extracorporeal circuit was clamped. The blood from the superior vena cava was returned to its natural course through the heart and lungs and washed out through the left ventricular vent any air trapped in the left side of the heart. When bubbles were no longer seen in the tubing leading from the left ventricle, the Tygon tube was removed and the stab wound in the apex of the left ventricle closed with interrupted sutures.

OPERATIVE RESULTS

A. Without Left Ventricular Vent.—Interatrial septal defects were produced and repaired by the technique just described in seventeen dogs without establishing a left ventricular vent to avoid air embolism. Eleven animals survived the perfusion and operative procedure. These animals were sacrificed between 7 and 157 days after operation (Table I).

In two instances (Dogs 524 and 527), air embolism of the coronary arteries occurred during the repair of the defect. The left coronary artery was completely filled with air and ventricular fibrillation occurred. Attempts at removal of the air by needle aspiration were unsuccessful. Consequently, the terminal portion of the anterior descending branch of the left coronary and marginal branch of the right coronary artery were divided near their points of termina-

TABLE II. PRODUCTION AND REPAIR OF INTERATRIAL SEPTAL DEFECTS WITH A VENT IN LEFT VENTRICLE

EXP. NO.	DATE	WT. OF DOG KG.	TIME VENAE CAVAL OCCLUDED MIN.	TIME HEART OPEN MIN.	SIZE OF DEFECT CM.	BLOOD DETERMINATIONS DURING LATTER PART OF CAVAL OCCLUSION							INTERVAL SACRIFICED (S) OR DEATH (D) DAYS	REMARKS
						OXYGEN SATURATION			ARTERIAL BLOOD PH	HEMATO- CRIT PER CENT	HEMOLYSIS IN PLASMA MG. HB/100 ML.			
						VENOUS BLOOD PER CENT	ARTERIAL BLOOD PER CENT	ARTERIAL BLOOD						
1953														
0-529	Jan. 21	13	44	31	1.7 x 1.7	46	101	7.36	39	85	S-22		Died in 10 hr. from P.O. hemorrhage	
0-530	Jan. 23	12	36	42	1.8 x 1.8	69	100	7.35	39	63	D		Died in 9 hr. from P.O. hemorrhage	
0-537	Feb. 12	23	49	54	2 x 2	56	103	7.09	40	63	D		Died in 16 hr. from P.O. hemorrhage	
0-538	Feb. 16	33	45	40	1.9 x 1.9	--	--	----	47	44	S-8		Died in 16 hr. from P.O. hemorrhage	
0-539	Feb. 18	16	40	48	2 x 2	40	102	7.38	39	66	D		Died in 20 hr. from P.O. hemorrhage	
0-540	Feb. 20	14	30	32	1.5 x 1.5	53	95	7.36	32	51	S-8		Died in 20 hr. from P.O. hemorrhage	
0-543	Mar. 2	30	50	54	1.8 x 2	70	103	7.36	39	80	D		Died in 20 hr. from P.O. hemorrhage	
Average		20	42	43		56	101	7.32	39	65				

tion and the coronary circulation permitted to pump itself free of air. The cut ends of the arteries were then ligated after the septal defect had been repaired and air could no longer be seen in the coronary arteries. Normal rhythm was established in Dog 524 by injection of 2 ml. of a 10 per cent solution of calcium chloride. A defibrillating shock was necessary in addition to calcium chloride in order to establish normal rhythm in Dog 527. Continuous massage was not necessary since the extracorporeal circuit maintained adequate systemic blood pressure and coronary circulation.

Dogs 499 and 526 died within ten hours after operation. Autopsy revealed large amounts of blood in the pleural cavities of both animals. Dogs 503, 506, and 523 died during the operative procedure from ventricular fibrillation resulting from air embolism of the coronary arteries. Dog 522 was alive twenty-four hours after perfusion. An intramuscular injection of morphine sulfate was given because the dog was restless and howling. The dog died fifteen minutes after the injection.

B. With Left Ventricular Vent.—A left ventricular vent was established before the production of the interatrial septal defect in seven dogs (Table II). In Dogs 529 and 530 the vent was placed in the angle between the circumflex and the anterior descending branches of the left coronary artery. In the remaining five dogs, a Tygon tube was placed within the left ventricle through a stab wound in the apex. Air embolism of the coronary arteries did not occur in any of these seven dogs. Four dogs died within twenty-four hours after operation. At autopsy a large amount of blood was found in the pleural cavities of all four dogs. Death was presumed to be due to uncompensated postoperative blood loss.

RESULTS AT AUTOPSY

All surviving dogs were sacrificed. The septal defects were completely closed in all animals. Grafts observed within twenty-four hours following repair were covered with a thin layer of fibrin (Fig. 3, *A*). Three weeks after operation the graft was firmly united to the margins of the defect, and all surfaces and suture material were covered with smooth glistening endothelium (Fig. 4, *A* and *B*). Histologically at this time there was very slight inflammatory reaction and beginning fibroplasia (Fig. 4, *C*). At the third and fourth month healing was complete (Fig. 5, *A*, *B*, and *C*) and (Fig. 6, *A* and *B*). The pericardial pedicles in Dogs 497, 498, 501, and 502 were contracted fibrous cords which obviously contributed nothing to the vascular nutrition of the graft. None of the free grafts were necrotic and none failed to unite with the margins of the defect.

Interatrial septal defects were created, but not repaired, in five control animals. After establishing a vent in the left ventricle, the right atrium was opened and a portion of the interatrial septum excised. The defects were all greater than 1 cm. in at least one axis. The wound in the right atrium was then sutured. It was always necessary to re-establish complete blood flow through the heart before all air could be displaced from the left ventricle through the ventricular vent.

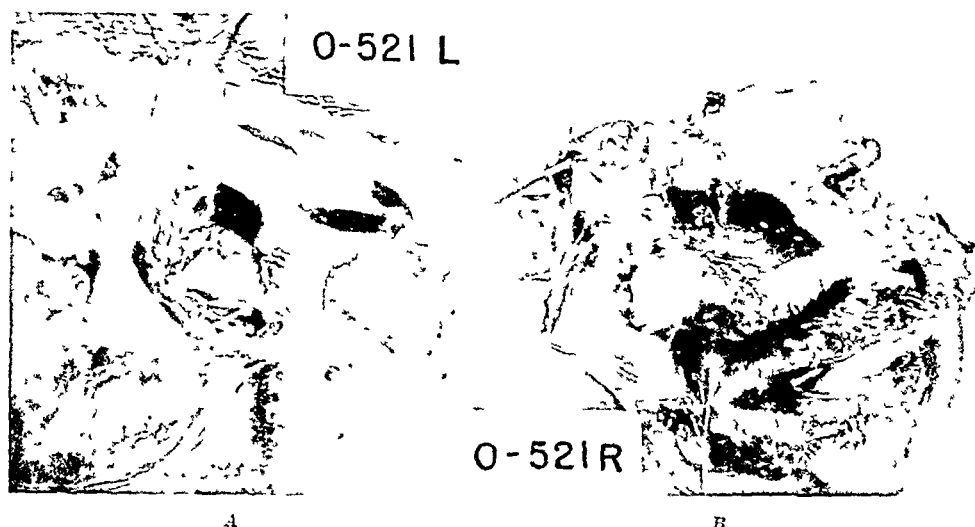


Fig 3—Twenty-four hours after repair of interatrial septal defect with free graft A, View from left atrium B, View from right atrium

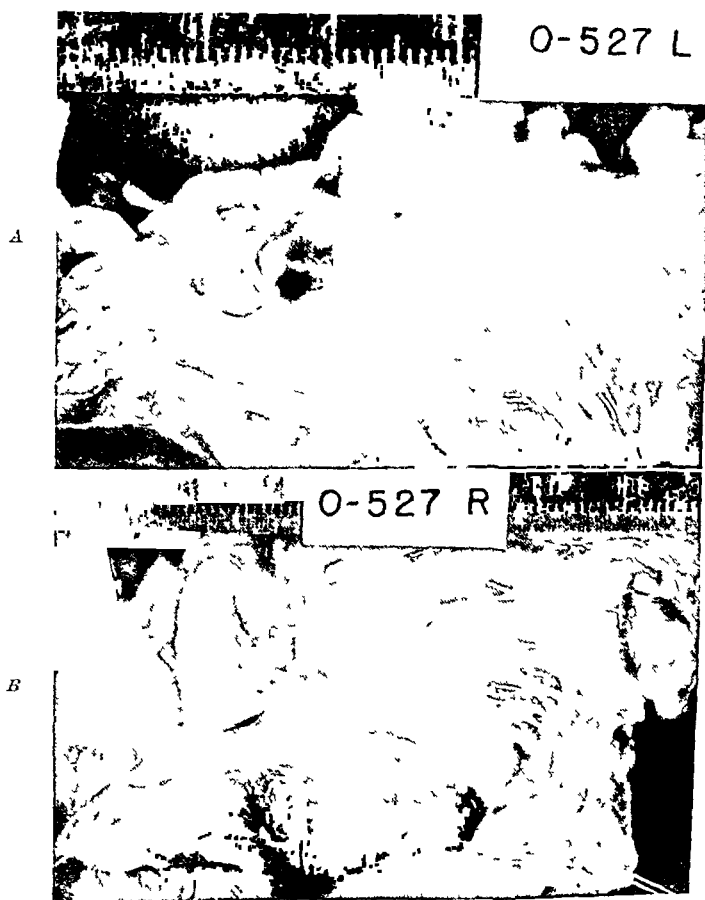


Fig 4—Seventeen days after repair of interatrial septal defect with free pedicled graft A, View from left atrium B, View from right atrium

Three of these animals survived the perfusion and operative procedure (Table III). Postoperatively, the soft systolic murmur which could be heard for a few days disappeared and no cardiac abnormality could be determined by auscultation. The animals were sacrificed at twenty-three, forty-four, and fifty-one days. The hearts were not enlarged. There were large, unhealed,

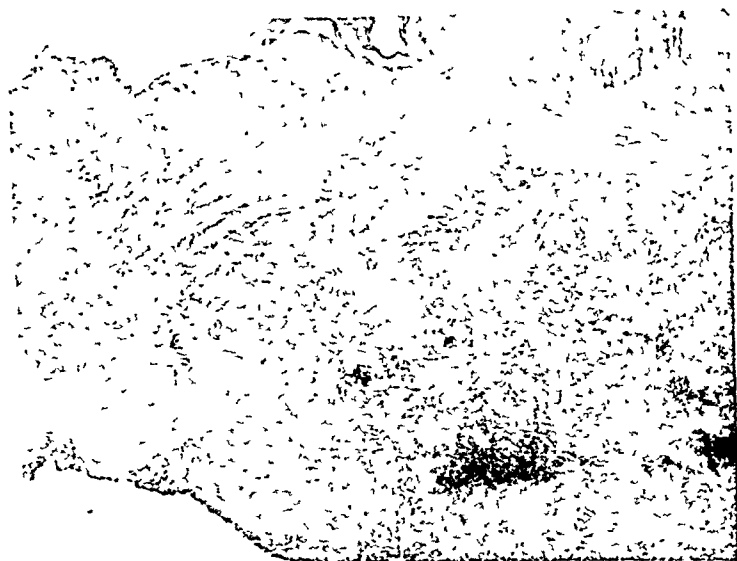


Fig 4C—Histologic appearance ($\times 20$)

interatrial septal defects in all three dogs. The defects were all approximately the same size as when they were made (Table III). The margins of the defects were smooth and glistening in appearance (Fig 7, A and B)

In the twelve dogs in which a left ventricular vent was established there was no evident damage to the endothelium lining the left ventricle. The mitral valve leaflets, chordae tendineae, and papillary muscles within the left ventricle were all normal in appearance at death or sacrifice. No thrombi were present in the left ventricular chamber and there was no subendothelial ecchymosis or hemorrhage.

PERFORMANCE OF THE APPARATUS

In twenty-six of the twenty-nine experiments reported here, the saturation of arterial blood with oxygen was 95 per cent or more. The failure to obtain adequate oxygenation in three early experiments of the series (0-408, 506, and 507, Table I) is probably attributable to an error in technique during establishment of the blood film on the screens of the oxygenator.

The rate of blood flow through the extracorporeal circuit expressed in ml. per kilogram of body weight of the animal per minute was similar to that of previously reported series.¹¹ Only the rate of blood flow from the venae cavae was measured. It varied between 48 and 166 ml. per kilogram per minute, averaging 83 ml. per kilogram per minute. As we have previously pointed out, the degree of saturation of the venous blood with oxygen is prob-

TABLE III. CONTROL INTERATRIAL SEPTAL DEFECTS

EXP. NO.	DATE	WT. OF DOG KG.	TIME VENAE CAVAE OCCLUDED MIN.	TIME HEART OPEN MIN.	SIZE OF DEFECT CM.	OXYGEN SATURATION		ARTERIAL BLOOD PH	HIMATO-CRIT PER CENT	HEMOLYSIS IN PLASMA MG. HB/100 ML.	INTERVAL BEFORE DEATH (D) OR SURVIVAL (S) DAYS	SIZE OF DEFECT AT TIME OF SACRIFICE	REMARKS
						VENOUS BLOOD PER CENT	ARTERIAL BLOOD PER CENT						
0-531	1953 Jan. 26	10.5	28	40	2.2 x 2.2	71	99	7.38	39	76	D		Died 36 hr., congested lungs
0-532	Jan. 28	11.5	23	20	1.6 x 1.8	47	98	7.36	37	32	S-51	1.4 x 1.2	
0-534	Feb. 2	12.0	22	19	1.5 x 1.5	70	103	7.47	42	49	D		Died 18 hr., congested lungs
0-535	Feb. 4	12.0	22	20	1.4 x 1.4	55	102	7.38	35	32	S-44	1.2 x 1.0	
0-541	Feb. 25	10.0	19	30	1.1 x 0.9	52	96	7.34	39	92	S-23	1.0 x 0.8	
Average			23	26		59	100	7.39	38	56			

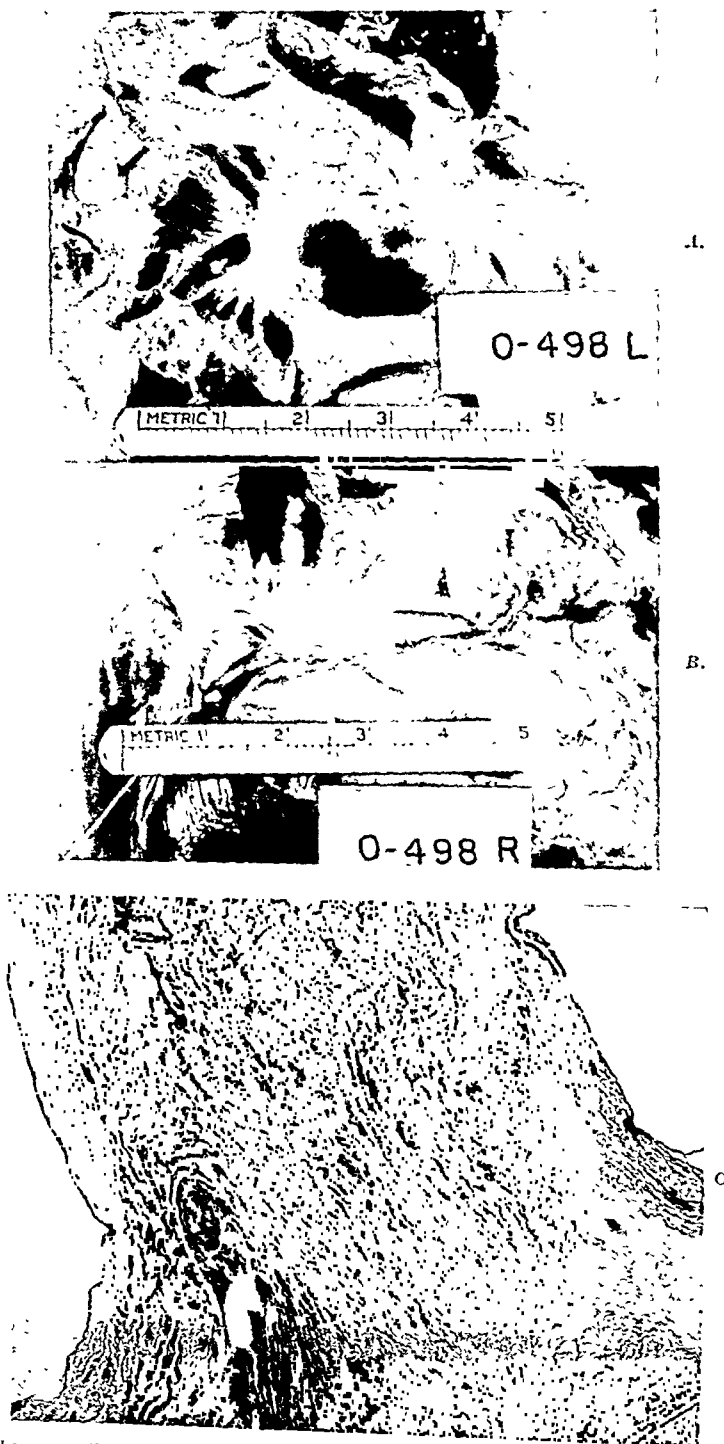
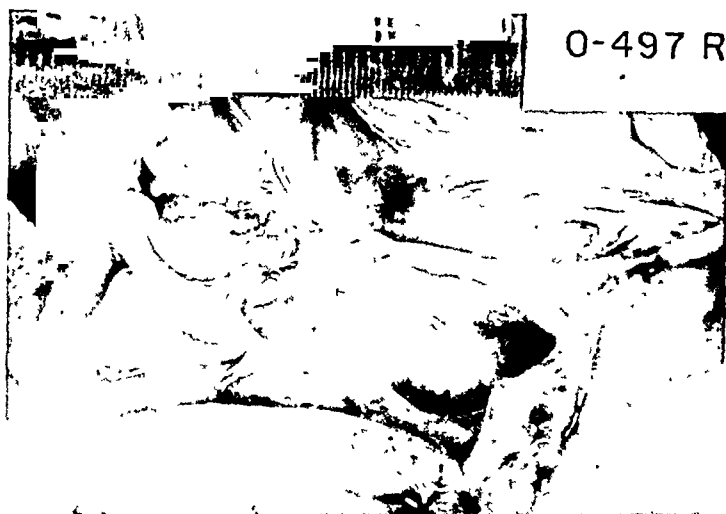
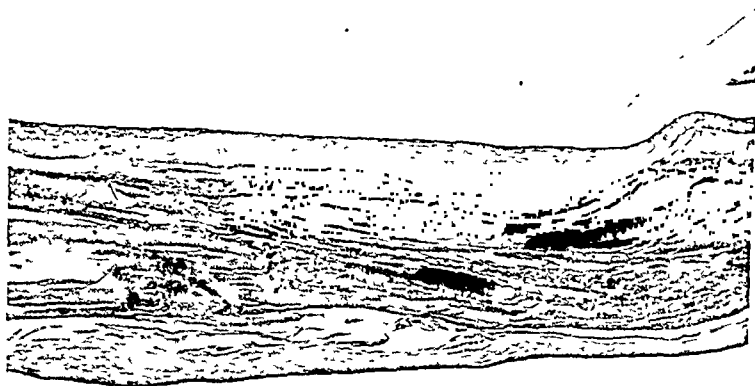


Fig. 5.—Three months after repair of interatrial septal defect with pedicled graft. *A*, View from left atrium. *B*, View from right atrium. *C*, Histologic appearance ($\times 20$).

ably a better index of tissue oxygenation than the relation of blood flow to body weight. In these 29 experiments the venous oxygenation saturation was between 40 and 50 per cent in eight experiments. In two of these experiments the oxygenator was inadequately saturating the arterial blood with oxygen. In the



A.



B.

Fig. 6.—Four months after repair of interatrial septal defect with pedicled graft. A, View from right atrium. B, Histologic appearance ($\times 20$).

other six instances the flow rate was probably insufficient to maintain normal tissue oxygenation even though the arterial blood supplying the tissues was between 95 and 102 per cent saturated with oxygen.

With one exception (0-537, Table II) the pH of the arterial blood was maintained at 7.3 or above. As has been shown¹¹ there is a slight tendency for fixed acids in the blood to increase during the course of a perfusion. This increase on

the average amounts to only 3 mM per liter. To compensate for this increase, the carbon dioxide tension of the blood is automatically reduced thus maintaining the pH at a near normal level.

The amount of hemolysis occurring during these experiments is lower than in any series we have previously reported. In four of the early experiments in this series the hemolysis was above 100 mg. per cent free hemoglobin in the plasma. In all other experiments it was well below this level.

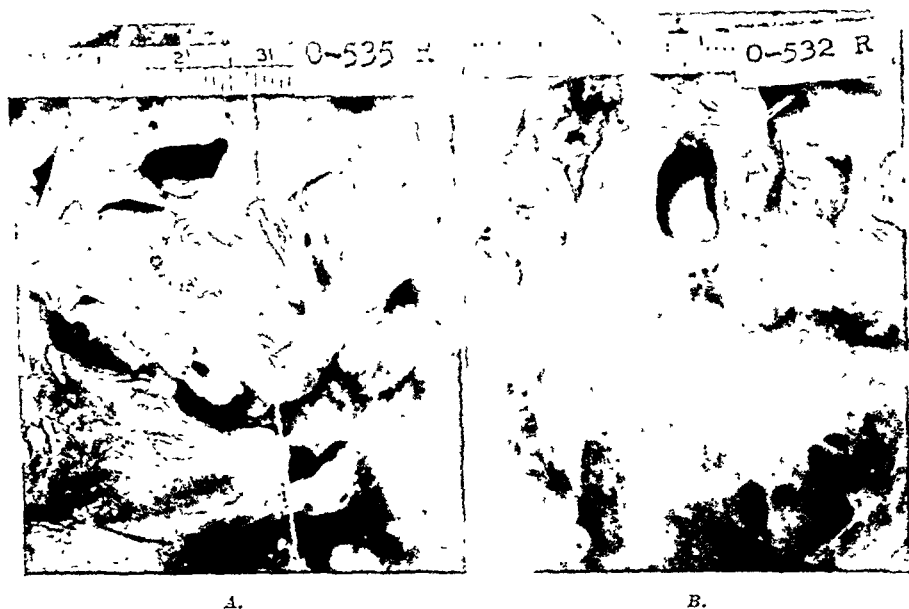


Fig. 7.—Patent interatrial septal defects. A, Forty-four days after production. View from right atrium. B, Fifty-one days after production. View from right atrium.

SUMMARY

1. The cardiorespiratory functions of twenty-nine dogs have been maintained by an extracorporeal blood circuit while the right atrium was widely opened and an interatrial septal defect created under direct vision.

2. The septal defect was not repaired in five dogs. Three of these survived and were sacrificed at twenty-three, forty-four, and fifty-one days. There was no spontaneous closure or significant decrease in size of the defects.

3. In twenty-four of the twenty-nine dogs, after creating the septal defect, it was immediately closed by a pericardial graft. Fourteen of the twenty-four dogs survived and were sacrificed at varying intervals up to 157 days. In all instances the defect was completely closed, the graft well healed and covered with endothelium on both sides.

4. In twelve consecutive experiments a plastic tube vent was placed in the left ventricular chamber during the period in which the left atrium was exposed to atmospheric air. Air embolism of the coronary arteries did not occur in any of these experiments.

5. In the seventeen experiments in which the left atrium was exposed to atmospheric air in the absence of a left ventricular vent, air embolism of the coronary arteries occurred in five dogs. Three of the five dogs died.

6. Ventricular fibrillation occurred in the five dogs with coronary air embolism. It did not occur in any other animal.

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(For discussion, see page 631.)

AN OXYGENATOR-PUMP FOR USE IN TOTAL BY-PASS OF HEART AND LUNGS

LABORATORY EVALUATION AND CLINICAL USE

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THE insistent challenge of surgical problems in cardiology and the potential application of corrective surgical measures have stimulated the search for mechanical substitution for the lungs and heart. Although this is a problem of immense complexity, the earlier progress by several investigators¹⁻⁴ has raised the hope that extracorporeal oxygenation and circulation can eventually be successfully employed in surgical cardiology. Results obtained through initial experiments with the Clark heart-lung apparatus have encouraged further investigations along these lines.

In experiments described in this report, it was not primarily planned to obtain long survival of the animal subjected to extracorporeal oxygenation and circulation. The first objective in this series was the continuation of laboratory evaluation of the Clark oxygenator-pump, with special reference to its efficiency in the processes of oxygenation and the elimination of carbon dioxide. The second objective was to acquire further experience in opening the cardiac chambers while the animal's functions of respiration and circulation are being carried out by this artificial means, that is, in the period that has been referred to as *the interval of total by-pass of the heart and lungs*. It was in the pursuit of this second objective that several new problems became apparent, and these unexpected developments necessitated a succession of modifications in the method of the experiment. More than that, these unexpected results had the fundamental effect of altering somewhat the hopeful anticipation of successful surgery in the widely opened and "bloodless" heart.

In the final part of this presentation a report is given of the clinical application of this machine. A complex defect in the cardiac septa was corrected by a direct operative procedure through a right auricular cardiomy. A full description of problems associated with this case is given. It is believed that the publication of certain inherent difficulties involved will be of assistance to those who are engaged in surgical research in cardiology.

From the Department of Surgery and the Department of Pediatrics, College of Medicine of the University of Cincinnati, Cincinnati, Ohio, and from the Fels Institute for Research in Human Development, Antioch College, Yellow Springs, Ohio.

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*Chairman of the Department of Biochemistry of the Fels Institute for Research in Human Development.

METHOD

Many of the details of these experiments were exactly as described in an earlier publication,⁵ and therefore only the significant innovations are given here. There was a much wider variation in body weight of the dogs. The lightest was 2.6 kilograms and the heaviest 23.2 kilograms. Pyribenzamine was included in the agents for premedication in every instance. Observations on body temperature were made by means of an esophageal thermometer, and the range was 27.8° C. to 32.5° C. during the period of total by-pass. Pentothal Sodium solution was used as the anesthetic agent in the latest studies. A polarograph⁶ was employed to detect changes in the oxygen tension in various tissues, most frequently in the musculature of the neck and the thoracic wall.

The system of cannulation for the drainage of the systemic venous blood did not include the L-shaped cannula employed in earlier experiments. The superior vena cava was drained by means of a plastic tube with multiple perforations, which was passed down through the right jugular vein. The inferior vena cava was drained by two similar catheters with multiple perforations. These latter instruments were inserted and passed upward through the femoral veins.⁷ Complete occlusion of the venae cavae was obtained by ligation of these vessels at the level of their junction with the right auricle.

Heparin was the only anticoagulant employed, and protamine was given at the conclusion of each experiment. The dose of the anticoagulant was determined by calculation from the estimated blood volume of the subject animal and the volume of blood required to fill the extracorporeal system; the calculated amount was 20 mg. of heparin per 1,000 ml. of blood. A simple protamine titration was carried out to determine the amount of this agent necessary to reverse the heparin effect at the conclusion of extracorporeal circulation.

Both femoral arteries were cannulated for the return of arterialized blood into the animal from the machine. Filters employing 325 mesh stainless steel screens, with a baked silicone coating, were inserted in the arterial line between the pumping chamber and the animal. (The filters were not used in every experiment since their effectiveness has not been fully established.) The system of cannulation for the withdrawal of the coronary venous return to the right half of the heart underwent some evolution during the study. The exposure gained through wide opening of the right auricle made cannulation of the coronary sinus a simple matter. However, there was often a relatively large volume of blood that returned via the several anterior cardiac veins,⁸ and, to deal with the problem raised thereby, it was necessary to alter the system. This was accomplished by the development of a suction tube with a rounded, closed end and a single lateral opening near the tip. (Even if the lateral opening is occluded by an endocardial surface, the suction applied through this tube may never exceed 10 cm. of water.) This suction instrument was inserted through the tricuspid valve after the auricle had been opened. The application of suction in the chamber of the right ventricle

accomplished more complete removal of the blood from the coronary system. That is to say, coronary blood returning to the right auricle gravitated through the open tricuspid valve into the ventricle, and the additional fraction of the coronary venous system drained by the Thebesian vessels into that chamber was also withdrawn by the aspirator. The complete unit for the collection of coronary venous blood was attached so that it served as a tributary to the inlet (venous) side of the extracorporeal circuit.

OBSERVATIONS ON OXYGENATION AND ELIMINATION OF CARBON DIOXIDE

There was a rapid reduction in body temperature of the dogs in the first quarter hour of "total" extracorporeal circulation. Observations on the oxygen content of samples of arterial and venous blood must be carefully interpreted with consideration of the existing hypothermic state.

The output of the mechanical heart, that is, the flow rate, is given in Table I. No difficulty was encountered in draining the venae cavae, and a free flow of venous blood was obtained away from the dog and into the extracorporeal circuit. (An increase in the suction required for venous pickup was invariably an early sign of the need for a small blood transfusion.) The criteria considered important in the control of this aspect of the experiments were the maintenance of the mean arterial pressure within a physiologic range and continual oxygenation which would ensure at least 90 per cent saturation of the stream returning from the apparatus into the animal. Therefore, when these criteria were satisfied, no additional effort was considered necessary to attain an arbitrary value for flow rate (cubic centimeters per minute per kilogram).

The determination of oxygen and carbon dioxide in blood samples was carried out in 18 experiments. The venae cavae were completely obstructed for sixty minutes and arterial and venous blood samples were drawn during this hour, as well as before and after it. The oxygenation that was accomplished in the extracorporeal apparatus is shown graphically in Fig. 1. From this it was apparent that there was no marked change during the hour of artificial oxygenation in the oxygen saturation of arterial samples from the animals. The per cent saturation remained in the range of 90, which was the approximate level of control values. Additional pertinent data are listed in Table I. The animal's body temperature and corresponding machine flow rates are correlative factors. An expression of oxygenation is given by the mean value of 3.67 c.c. per minute per kilogram of body weight.

The elimination of carbon dioxide in the extracorporeal circuit is shown in Fig. 2. The carbon dioxide content of arterial and venous samples varied somewhat in the pre-by-pass controls. There was no accumulation of carbon dioxide during the one-hour interval of caval occlusion. (Supplementary data are given in Table I.) Another measure of the elimination of carbon dioxide is the mean value of 2.99 c.c. per minute per kilogram of animal weight.

METHOD

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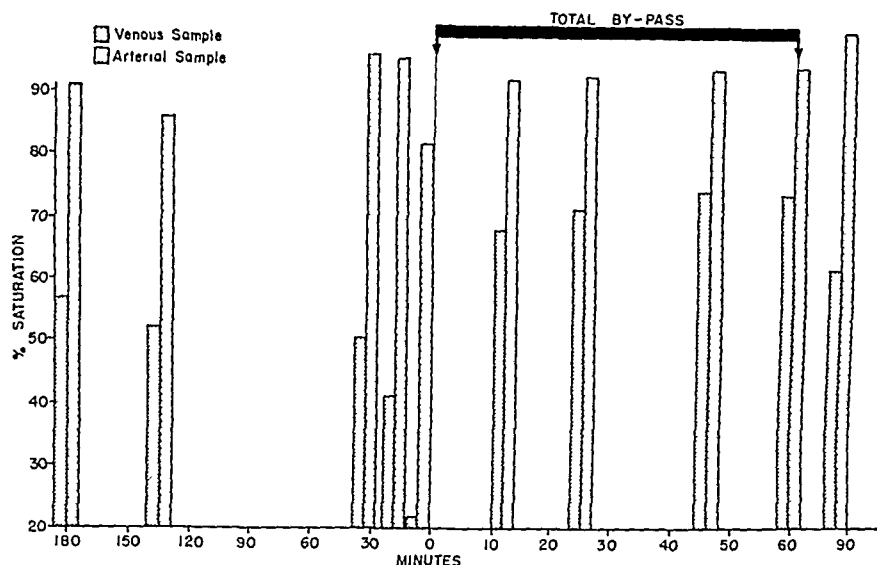
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CARDIOTOMY (RIGHT AND LEFT AURICLE) DURING "COMPLETE" BY-PASS

The oxygenator-pump which was found to be an efficient mechanical substitute for the lungs and heart in laboratory experiments has made visual exploration of the cardiac chambers of dogs a feasible procedure. A long incision

Fig. 1.

OXYGEN



CARBON DIOXIDE

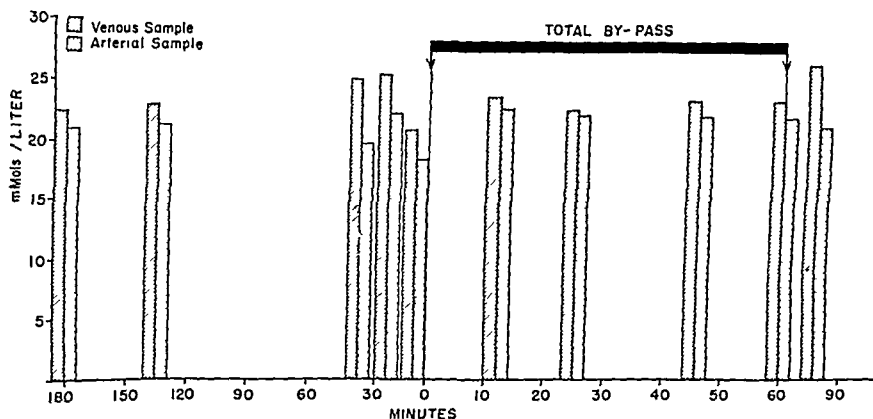


Fig. 2.

Fig. 1.—Oxygen saturation of arterial and venous samples during total by-pass. Each column represents an average of 3 to 5 analyses of samples drawn before and following the total by-pass. The columns in the interval of by-pass represent an average of from 5 to 12 analyses. The figure records the analyses of 105 samples (52 arterial and 53 venous).

Fig. 2.—Carbon dioxide content of arterial and venous samples during total by-pass. Each column represents an average of 3 to 5 analyses of samples drawn before and following the total by-pass. The columns in the interval of by-pass represent an average of 5 to 11 analyses. The figure records the analyses of 104 samples (52 arterial and 52 venous).

TABLE I. FLOW RATES, OXYGENATION AND CARBON DIOXIDE DETERMINATION

WEIGHT OF DOG (KG.)	BODY TEMPERATURE (°CENTIGRADE)	TIME AFTER START OF TOTAL BY-PASS (MINUTES)	FLOW (C.C. PER MINUTE PER KG.)	OXYGENATION (C.C. PER MINUTE PER KG.)	CO ₂ ELIMINATION (C.C. PER MINUTE PER KG.)
11.4	27.8	9	79.8	1.84	2.39
	27.5	27	91.2	3.47	0.18
14.5	30.3	15	98.6	3.35	1.48
	30.5	45	98.6	2.47	1.97
13.2	31.0	29	98.5	2.56	2.46
8.6	28.1	35	97.7		3.52
16.0	32.0	25	97.5	3.61	3.9
	31.5	45	87.5	4.64	4.55
12.0	31.2	41	105.0	3.47	5.15
10.0	31.0	44	90.0	3.06	2.97
11.1	32.4	17	118.9	4.99	1.66
	32.0	35	108.1	3.24	4.54
	31.2	56	118.9	3.57	3.57
23.2	29.7	48	103.4	3.62	1.76
	29.5	55	103.4	3.00	4.14
10.0	29.0	61	144.0	4.46	3.31
16.3	31.4	15	88.3	3.71	3.62
	30.8	10	88.3	4.15	3.71
11.4	29.6	48	126.3	3.16	1.52
15.0	32.5	14	86.7	4.77	3.73
	32.0	39	91.0	5.19	3.37
14.1	29.8	45	92.2	1.94	3.50
	29.6	59	92.4	2.30	2.12
3.9	28.2	35	135.9	5.03	4.21
3.39	28.0	33	129.8	4.80	2.60
2.6	31.1	11	84.6	5.33	1.78
Mean			102.2	3.67	2.99

extending from the base of the right auricular appendage to the insertion of the inferior vena cava was made in 8 dogs. With total occlusion of both cavae, the lowest portion of the right auricle was still usually flooded by the volume of venous return from the coronary sinus, from the anterior cardiac veins, and from other coronary venous channels draining into that chamber. The volume of this fraction of the coronary venous return was estimated in several experiments. The results given in Table II do not represent an accurate measurement of coronary blood flow; they serve only as a quantitative expression of this characteristic of the opened and by-passed heart, an aspect not sufficiently emphasized heretofore. In every instance, this volume of coronary venous blood was large enough to disappoint greatly the surgeon who had been expecting to operate in a "bloodless" field within the heart.

Incision of the wall of the right auricle did not alter the contractions of the left auricle or the ventricles. The blood which drained from the coronary sinus often shot into the lower part of this auricular chamber in jets synchronous with ventricular systole. This fraction, together with the other portions of coronary venous return, rapidly coursed over the lower rim of the tricuspid orifice into the right ventricle. The stream of blood gravitating down the dependent portion of the auricle and over the tricuspid rim was necessarily turbulent. This activity caused the mixture of some air with the blood, to

form bubbles which were swept along into the right ventricle. It was clear that this hazard of bubbles in the right ventricle accompanied every extensive right auricular cardiectomy.

TABLE II. VOLUME OF CORONARY VENOUS BLOOD DRAINED FROM OPENED HEART DURING "TOTAL BY-PASS"

WEIGHT OF DOG (KG.)	MEAN ARTERIAL PRESSURE (MM. Hg)	BODY TEMPERATURE (°CENTIGRADE)	ARTERIAL O ₂ (%) SATURATION	PULMONARY ARTERY	AORTA	AURICULAR SEPTUM	MAXIMUM VOLUME CORONARY VENOUS BLOOD ASPIRATED (% TOTAL MACHINE OUTPUT)
<i>Aspiration of Coronary Sinus</i>							
8.6	85	28.6	100	Open	Open	Intact	10 (1.19%)
13.2	95 to 115	28.1		Open	Open	Intact	25 (2.66%)
<i>Aspiration of Dependent Portion of Right Auricle</i>							
12.0	80 to 120	31.5	95.9	Open	Open	Intact	60 (4.76%)
10.0	95 to 105	32.0	100.0	Open	Open	Intact	25 (2.5 %)
14.3	80	32.5		Open	Open	Open	12.5 (1.3 %)
13.0	65 to 70	31.8		Open	Open	Intact	40 (3.3 %)
	73 to 75	31.1		Closed	Closed	Intact	7 (0.58%)
	70 to 75	30.7		Open	Open	Intact	240* (18.1 %)
<i>Aspiration of Right Ventricle</i>							
23.2	60 to 120	30.1	91.8	Open	Open	Intact	333 (13.9 %)
10.0	80 to 94	30.3	94.0	Open	Open	Intact	73 (5.0 %)
16.3	65 to 80	31.6	94.0	Open	Open	Intact	200 (13.9 %)
	80	30.6	93.8	Open	Open	Intact	280* (20.0 %)
11.4	70 to 100	29.6	95.0	Open	Open	Intact	190 (13.2 %)
15.0	40 to 100	32.5	77.5	Open	Open	Intact	170 (13.1 %)
14.1	80 to 150	30.0	81.1	Open	Open	Intact	140 (10.8 %)
2.6	75 to 80	30.1	108.8	Closed	Closed	Intact	26 (10.3 %)
4.9	100	29.8		Closed	Closed	Open	40 (13.3 %)

*Measurements taken during ventricular fibrillation.

The technical problems were increased still further by excision of the interauricular septum. This was so because, following the excision, the turbulent flow of blood and resultant air embolism involved the left half of the heart as well. The entire interauricular septum was removed and the two auricles were converted into a single, wide-open chamber in 8 dogs. The coronary venous inflow of the right auricle was admixed immediately with the richly oxygenated blood of the left auricle. The contents of the left auricle consisted of venous drainage from the bronchial vascular system, since the pulmonary artery flow had been interrupted and there was no patent ductus. Fractional measurements were not possible, but the volume of bronchial arterial flow which returned via the pulmonary veins was surprisingly large and could not be disregarded. However, this increment of "venous blood" to be drained away from the "totally by-passed" heart was the lesser of the complications which followed excision of the auricular septum. The blood in the active left auricle was soon mixed with air, just as had occurred in the right auricle, and it was but a short time until this air-blood mixture had coursed through the mitral valve and out into the aorta.

This description indicates the two principal problems encountered upon opening the right or both auricles. The first was the efficient drainage of the

venous blood of the intrinsic (coronary) cardiac circulation. The second was the admixture of air and this intrinsic venous blood with resultant air embolization. The following steps were taken successively in an effort to solve these problems. The first problem, the excessive volume of coronary venous return to the right side of the heart, was dealt with initially by catheter drainage of the coronary sinus. In several animals, however, the coronary return through vessels *other* than the coronary sinus comprised so large a volume that the auricle was inadequately emptied by simple coronary sinus drainage.^{9, 10} The next method that was tried for emptying the right auricle was continuous suction in the dependent portion of the chamber. At that stage in the evolution of the procedure, the hazard of air embolism became more apparent and a further modification in method was tried. This was to maintain continuous suction in the right ventricle by means of one of several different glass and plastic catheters, which served to withdraw the coronary venous blood. It also prevented the propulsion of air emboli into the pulmonary artery, since the pressure in the right ventricle was reduced by continuous suction and the instrument separated the leaves of the tricuspid valve. The "blind" cannulation of the chamber through the tricuspid was somewhat hazardous because of the possibility of trauma to the endocardium. In addition to this risk, it was soon noted that no matter what aspirating device was employed for that purpose, it added to the complexity of a restricted operative field.

An alternate procedure which lacked these disadvantages was temporary occlusion of the pulmonary artery. This vessel was occluded by means of a ligature just beyond the pulmonic valve. After occlusion, an incision was made before the auricle became overdistended with coronary venous return. Satisfactory emptying resulted after the aspirator was placed in the dependent portion of the auricle. There was some regurgitation through the tricuspid valve during the period of pulmonary artery occlusion, but embolism of air into that vessel was effectively prevented.

As has been mentioned, removal of the interauricular septum exposed the major circulation to the hazard of air embolism. This complication was not prevented by continuous aspiration of the bronchial and coronary venous blood from the dependent portion of the left auricle. Frequently a mixture of air and blood passed the mitral valve and soon appeared in the coronary arteries. After failure of this first measure, the next method tried was that of total occlusion of the aorta. Obstruction of the aorta at the lowest level of its extracardiac portion prevented propulsion of air emboli into the major circulation. Closure of the aorta, however, interrupted the filling of the coronary arteries from the arterial stream of the extracorporeal circuit. It is true that in some dogs the coronary circulation could be maintained, despite interruption of flow along the ascending aorta, if the bronchial system of arteries and veins were to return an adequate volume of blood to the left half of the heart. In several dogs in the present series, however, this bronchial circuit did not supply a volume adequate for coronary filling, and complete closure of the aorta produced serious changes in the color and tone of the myocardium after only two to three minutes.

Failure of this second method led to the trial of a third precaution against the development of air embolism. The aorta was catheterized with an additional plastic tube of small diameter. The tip of this instrument was localized just above the aortic valve, thus serving as a special channel for the return of arterialized blood from the apparatus to the proximity of the coronary orifices. An adequate flow of arterial blood into the coronary circuit was thus assured, and the aorta was then occluded in its ascending portion by ligation and compression of its walls around the central catheter. The mixture of air and blood which passed through the mitral valve from the opened auricles was rapidly ejected by the ventricle, and shortly thereafter air embolization of the coronary arteries was again apparent. This method had maintained coronary artery filling by means of the separate axial catheter from the machine. It failed, however, to prevent the ventricle from ejecting blood, with air admixed, into the occluded root of the aorta. Thus the problem of air embolism remains unsolved; but there is no reason to accept it as an unpreventable hazard, inasmuch as several obvious methods for the prevention of air embolism have not yet been given adequate trial.

The drainage of blood from the open cardiac chambers may be accomplished with less difficulty because of the unique capacities of the Clark apparatus. These are the coalescence of bubbles and the continuation of pumping without interruption, despite the entrance of rapidly varying volumes of blood into the venous side of the circuit. These qualities of the machine make it appear now that the withdrawal of a large volume of blood from the opened (and totally by-passed) heart can readily be accomplished. What is more important, this volume of blood from the intrinsic (coronary) and bronchial circulations can be channeled directly into the extracorporeal circuit, so that the effect of an even brief reduction in the volume of extrinsic circulation is entirely prevented.

CLINICAL USE OF THE OXYGENATOR-PUMP

The patient, a 4-year-old white boy, had been under medical observation most of his life. Several weeks after birth, a bulging deformity was noted in the precordial area. In his first year there were severe infections of the respiratory tract, one of them developing into bronchopneumonia which necessitated hospitalization. There were similar episodes in the patient's second and third years, and during that period one of the infections was complicated by congestive heart failure. Following that, he continued on 0.5 mg. of digitoxin daily; his exercise tolerance became so poor, however, that in his fourth year he could walk only about 25 yards. He slept poorly because of orthopnea and a persistent, nonproductive cough.

The boy's weight was 12 kilograms, his height 95 cm., and he appeared to have been chronically ill. His jugular venous pressure was elevated to 5 cm. above the sternal angle; and the liver edge, which did not pulsate, was 6 cm. below the right costal margin. Blood pressure was 94/50 mm. Hg in both arms and 110/60 in both legs, and the pulsation of the femoral arteries was normal.

The precordial area bulged markedly and the apex was in the sixth left intercostal space in the anterior axillary line. A coarse systolic thrill was palpable down the left sternal border and a grade 4 systolic murmur was audible over the precordium and the back. The second sound was widely split, but there was no diastolic murmur.

Examination of the peripheral blood, urine, and erythrocyte sedimentation rates gave normal values. The electrocardiogram revealed incomplete right bundle branch block. Chest roentgenograms showed cardiac enlargement and pulmonary overcirculation. The total blood volume was estimated to be 990 c.c.

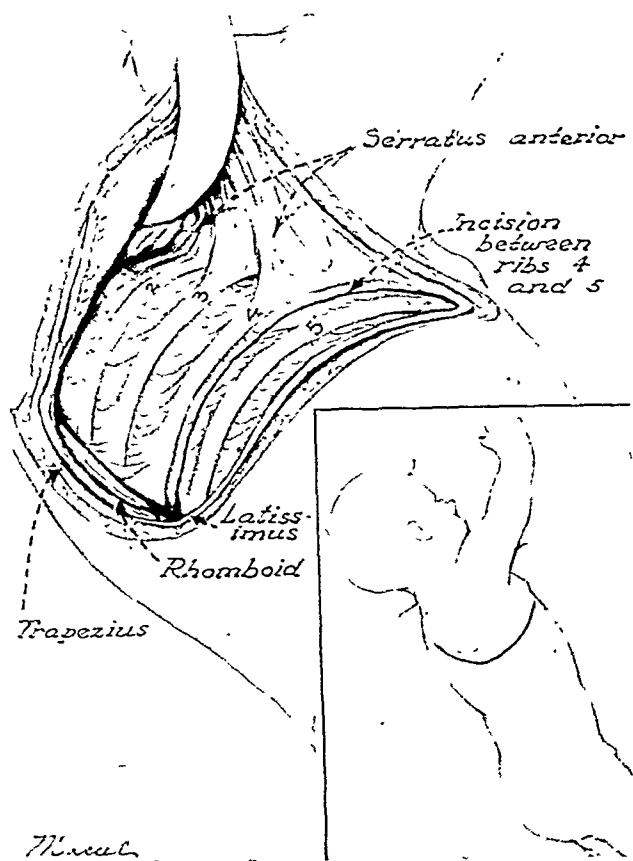


Fig. 3.—Position of patient on table, and location of posterolateral incision.

Cardiac catheterization five months prior to surgery gave the following results:

	Pressure	O ₂ content
Pulmonary artery	92/38 mm. Hg	11.8 vol. %
Right ventricle	92/10	11.7 vol. %
Right auricle (mean)	10	11.9 vol. %
Superior vena cava	—	10.0 vol. %

Peripheral arterial oxygen saturation was 97 per cent; the cardiac output, 5.8 liters per minute; the calculated left-to-right shunt, 3.1 liters per minute. The working diagnosis was a defect in the interauricular septum, and surgical closure was planned because of the precarious condition of the child.

The patient was anesthetized with Pentothal Sodium solution, following which oxygen and ether were given through a closed endotracheal system. A moderate cooling effect was obtained by applying bags of cracked ice, and the operation was begun after the rectal temperature had been reduced to 90° F. The incision employed and the initial

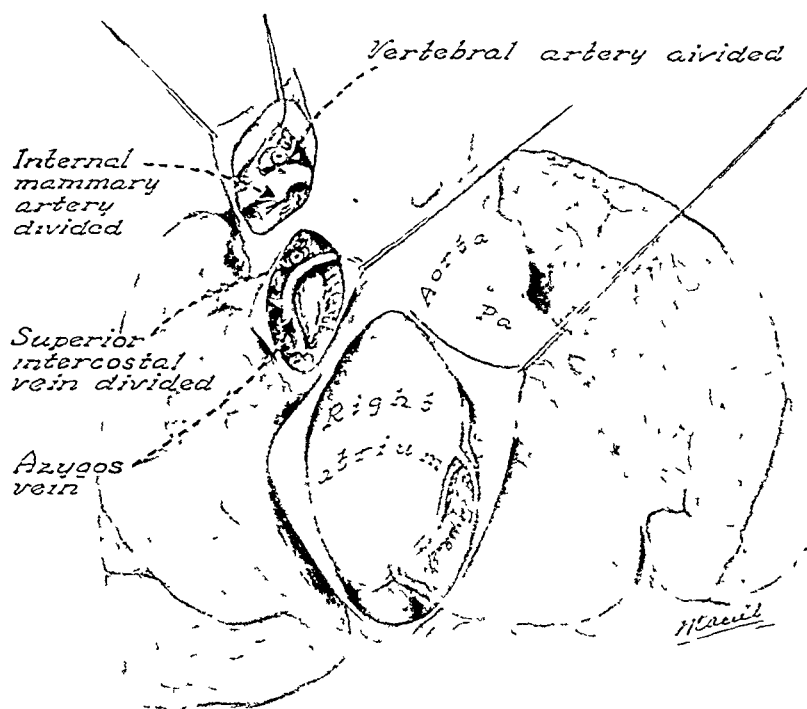


Fig 4—Exposure of right atrium, the subclavian artery and azygos vein for catheterization

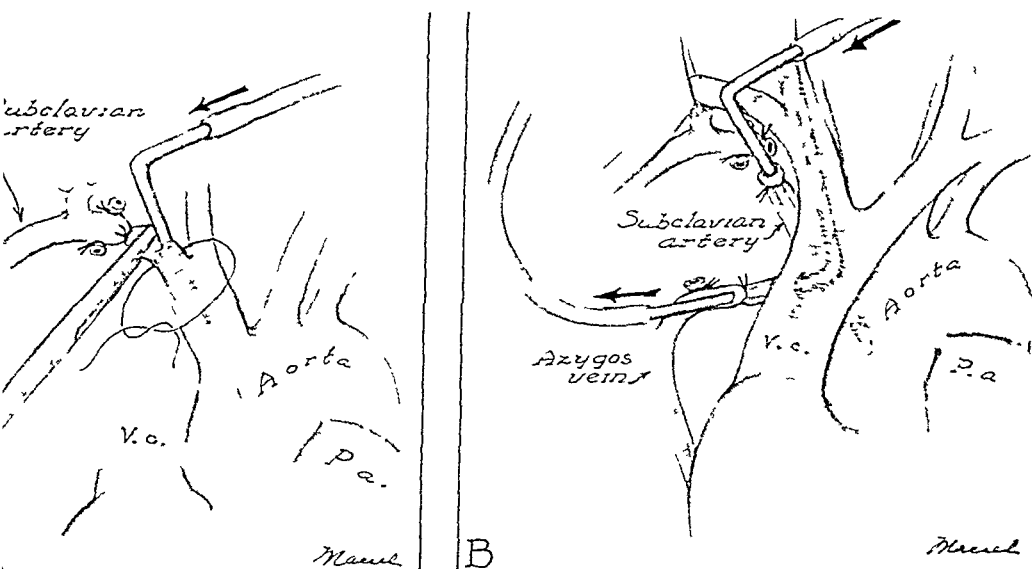


Fig 5—A, Cannula for return of blood from extracorporeal circuit into aorta B, Catheter for drainage of the superior vena cava

steps taken in the dissection within the chest are shown in Figs. 3 and 4. The catheter system for venous drainage included three plastic tubes with multiple perforations. Two of these were inserted via the saphenous veins into the inferior vena cava, their tips lying near the level of the renal veins. The other catheter was then passed through the

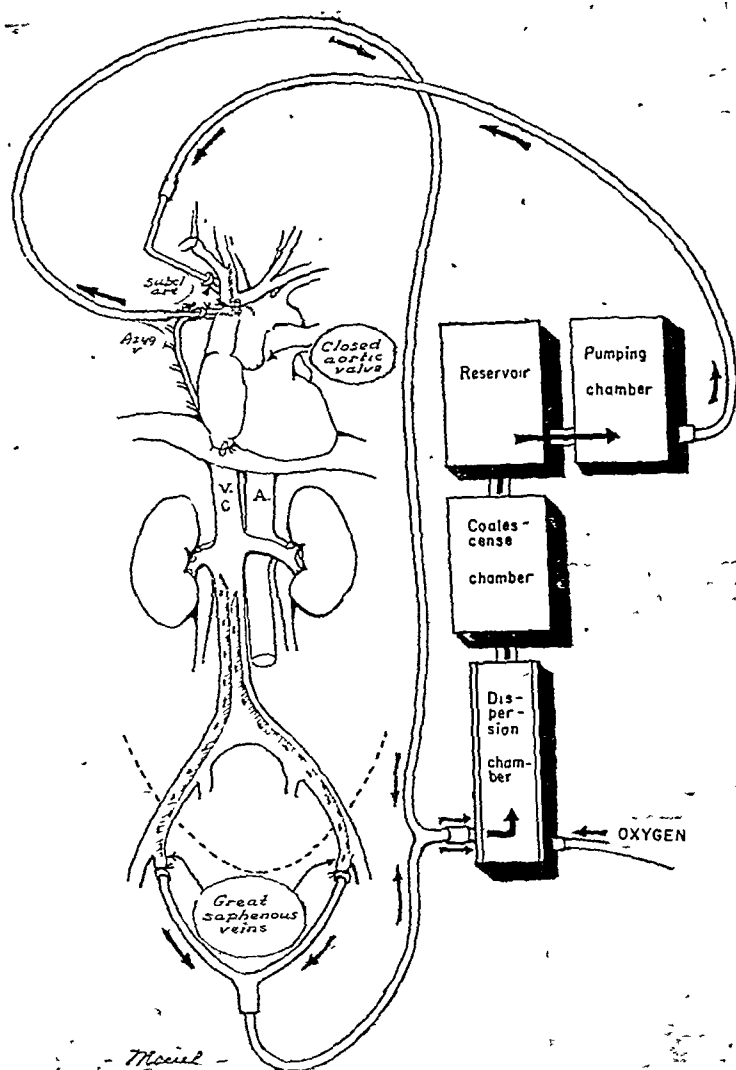


Fig. 6.—Oxygenator-pump showing attached venous pickup catheters and channel for return of blood into aorta.

azygos vein and upward along the full length of the superior vena cava. The channel for return of arterialized blood was a single plastic cannula, which was inserted through the subclavian artery and advanced until its tip was in the ascending aorta (Fig. 5).

The entire extracorporeal system was filled with blood, and care was taken to ensure complete replacement of all that had been lost up to that stage of the operation.

Three units of decalcified blood* (approximately 1,200 c.c.) and one unit of blood collected in the standard manner with ACD† were used for this. Fig. 6 gives in diagrammatic form the complete extracorporeal circuit and its attachments to the vena cavae and the aorta.

Extracorporeal circulation was started and the flow rate slowly accelerated, so that after ten minutes the rate was 900 to 1,200 c.c. per minute. The superior and inferior venae cavae were then occluded, and the wall of the right auricle was opened through a long incision. This chamber had seemed quite collapsed, as if it were empty, but within a few minutes after entering it the entire area was flooded by the great volume of returning coronary venous blood. The catheter system provided for the withdrawal of this coronary outflow was not adequate to handle the volume encountered. This insufficiency

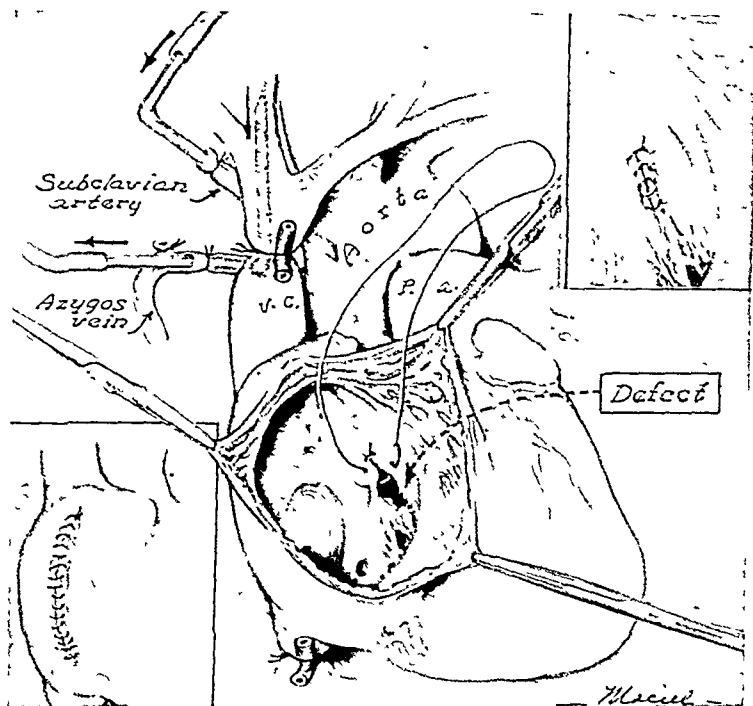


Fig. 7.—Exposure of septal defect through right auricular cardiotomy in by-passed heart.

resulted in a delay in returning the venous blood to the extracorporeal circuit and, as a result, the arterial pressure fell to shock levels. The inadequate system for draining away all the intrinsic blood was compensated for, in part, by several improvisations, but an uninterrupted and adequate machine flow could not be maintained. The volume of coronary blood aspirated from the right auricle was not less than 250 c.c. per minute. The arterial pressure did not return to a satisfactory level until approximately fifty minutes after the onset of shock.

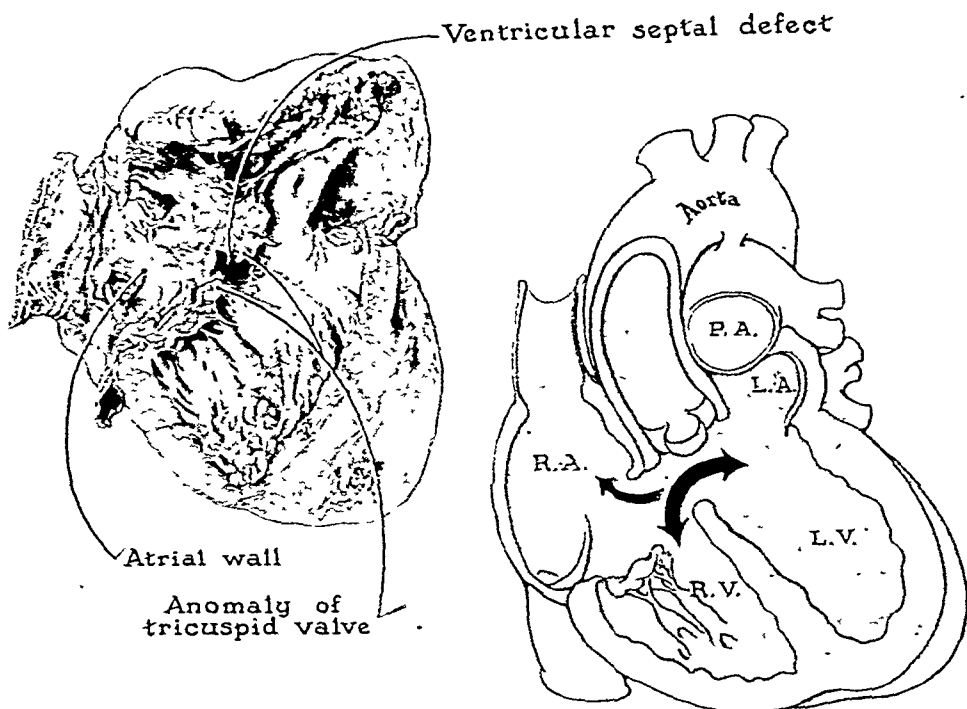
The opening in the right auricle made it possible to close the defect by sutures placed under direct vision. The exposure that was gained and the simple method of closure are shown in Fig. 7. The complex anatomical nature of the defect and its effect upon the dynamics of the ventricles and the right auricle may be seen in Fig. 8. Despite the difficulty with an overwhelming coronary venous outflow, it was necessary to hold

*Fenwal Ion Exchange Blood Pack, Fenwal Laboratories, Inc., Framingham, Mass.

†Baxter Transfuso Vac Container, Baxter Laboratories, Inc., Morton Grove, Ill.

the auricle open for only seventeen minutes. The machine flow was 1,440 c.c. per minute after closure of the auricular wall, and the by-pass was terminated after a total of thirty-three minutes.

Protamine solution was then given intravenously and all catheters and cannulae were withdrawn. The pleural space was drained and the chest wall was closed in the standard manner. A dilute solution of Neosynephine was given intravenously, as well as a transfusion of 250 c.c. of blood. Eight hours following operation the child was able to move his extremities and take sips of water. Sponging was required to prevent serious hyperthermia. He remained anuric and sixteen hours after closure of the defect he died.



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Fig. 8.—Ventricular septal defect and anomaly of tricuspid valve as viewed through opened right auricle and ventricle.

There was a small amount (90 c.c.) of blood in the right pleural space and some atelectasis in the dorsal portions of both lungs. The ventricular septal defect (1.5 cm. in diameter) had been closed by the surgical procedure. After removal of all sutures, it was shown that the right auricle communicated directly with the cavity of the left ventricle, because of the incomplete septal cusp of the tricuspid valve. There was no defect in the septum between the auricles. A fresh infarct was found in the upper pole of the right kidney. The brain was not examined, and therefore the possibility of cerebral air embolism was not expected.

The many observations made during this procedure could not all be included in this presentation, but the following summary covers the most important features. The pre-operative diagnosis was not confirmed, but rather a defect high in the ventricular septum and an anomaly causing marked incompetence of the tricuspid valve were encountered after the by-passed heart was opened. A massive flood was caused by the coronary

venous return. The oxygenator-pump functioned perfectly, despite irregularity in the flow into its venous side, and despite the aspiration of very great amounts of air along with the blood from the intrinsic cardiac circulation. The explanation for the large volume of coronary venous return is a matter of fundamental importance. It is certain that a high degree of arterial oxygen saturation was present at the time the cardiectomy was started. The cerebrum, and possibly the myocardium as well, suffered hypoxia in the period of hypotension caused by the temporary reduction of machine flow rate. After suture of the septal defect and termination of the extracorporeal circulation, the heart resumed the emptying of its filled chambers and continued to beat normally. Death was caused by cessation of function of the higher centers. No sign of air embolism was found at the limited necropsy, and blood cultures taken at the conclusion of extracorporeal circulation proved to be sterile.

SUMMARY

1. Some innovations in the experimental method were discussed.
2. The machine flow rates and animal temperatures in 17 experiments were tabulated.
3. Results given of analysis showed that oxygenation was obtained at the rate of 3.67 c.c. per minute per kilogram, and that carbon dioxide was eliminated at the rate of 2.99 c.c. per minute per kilogram.
4. Experiences in dealing with the coronary venous return and the hazard of air embolization in the opened and "by-passed" heart were presented.
5. A description was given of an operation on a child with a defect in the ventricular septum. In the surgical procedure his heart was by-passed and the defect was closed by a direct approach through the opened right auricle. The problem created by excessive coronary venous return was discussed. The child's death, sixteen hours later, came as the result of a period of hypotension during the operation or cerebral air embolism.

The authors wish to express their gratitude to Drs. Thomas Largen and Frederic N. Silverman for their assistance with many problems encountered over a long period of time. The technical assistance contributed by Mrs. Molly Kaplan, Miss Ruth Parker, Miss Zena Taylor, and Miss Carol Limbert was essential to the completion of this work. Student anesthetists from the Department of Anesthesia of the Cincinnati General Hospital, under the direction of Miss Mary Alice Costello, were most helpful in carrying out the experiments.

The Vernet Equipment Foundation of Antioch College made available several valuable pieces of equipment for use in the laboratory.

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DISCUSSION ON "THE PRODUCTION AND REPAIR OF INTERATRIAL SEPTAL DEFECTS UNDER DIRECT VISION WITH THE ASSISTANCE OF AN EXTRACORPOREAL PUMP-OXYGENATOR CIRCUIT," BY DR. BERNARD J. MILLER, DR. JOHN H. GIBBON, JR., DR. VICTOR F. GRECO, DR. BURGESS A. SMITH, DR. C. HAROLD COHN, AND DR. FRANK F. ALLBRITTEN, JR.; AND "AN OXYGENATOR-PUMP FOR USE IN TOTAL BY-PASS OF HEART AND LUNGS," BY DR. JAMES A. HELMSWORTH, DR. LELAND C. CLARK, JR., DR. SAMUEL KAPLAN, AND DR. ROGER T. SHERMAN

DR. CLARENCE DENNIS, Brooklyn.—In 1947, work was started by a group of us at the University of Minnesota in an effort to develop a heart-lung apparatus of the type you have heard about today. Our original orientation was provided by Dr. Gibbon and his group in Philadelphia; we have enjoyed his friendship and exchange of data since that time, I think to the benefit of both groups, but I know to the benefit of ours. It is my opinion that Dr. Gibbon is not only the pioneer in this field, but that he unquestionably is the leader at the present time as well.

Initially we considered pumps to shunt blood around one side of the heart alone, but clinical indications for such applications seemed to us to be rare, and the propriety of application in those cases in which pumps have been used clinically is a matter of grave doubt at the present time.

In the spring of 1951, having achieved a state of development which permitted fairly regular creation and closure of interatrial septal defects in dogs, we were joined by Dr. Richard Varco in an effort to close such defects in failing hearts in children. The first case was reported by the group of us two years ago at the meeting of the American Surgical Association. It is of interest that that case concerned a patient with an atrial septal defect, and that the amount of return of blood to the right atrium from the intrinsic circulation of the heart was reported by us at that time to be in excess of 250 c.c. per minute also.

The second case was undertaken some weeks later. Under direct vision snug closure was easily accomplished. (Slide.) The difficulty in this case arose from several sources. This would apparently have been the first successful clinical closure of such a defect, if a member of the team had not failed to switch on a level control mechanism, an oversight which resulted in the forcing of oxygen into the aorta with obvious gas in the coronary and carotid arteries. The circulatory difficulties which resulted led to very severe pulmonary edema. However, continued support by virtue of femoral cannulas, to the extent of about 200 c.c. per minute, led to return of normal blood pressure, a strong heart beat, and an apparently normal electrocardiographic tracing. Although cerebral damage was apparent, the chest was closed, and the patient survived with the support of the oxygenator until the end of the day, at which time death occurred.

(Slide.) This experience and our finding of the disastrous effects of the inadequacy of chemical sterilization have led us to spend the intervening twenty months in design and construction of a new apparatus, which is virtually completely automatic; the blood-bearing unit of this apparatus can be autoclaved after complete assembly. We have been delayed many months by the move from Minneapolis to Brooklyn, but hope now for early resolution of some of the remaining problems.

I have visited with Dr. Clark and his associates, Dr. Gollan and Dr. Gupta of Yellow Springs, Ohio, and have been unable to escape the dread of the effect of gas bubbles in the blood returning to the septum. I should like to ask Dr. Helmsworth if he is satisfied that failure to find evidence of air embolism at autopsy is satisfactory removal of the possibility of this as a source of difficulty.

DR. JOHN H. GIBBON, Jr., Philadelphia.—I merely rise to say that while we have used this method of avoiding air embolism in the systemic arteries, we are not at all sure that it is going to prove eventually to be the best or the only method.

About six months ago Senning of Crafoord's laboratory published a paper in which he produced ventricular fibrillation deliberately in order to avoid having the left ventricle pump the air which it contained during the creation and closure of interatrial septal defects. Following the closure of the atrial septal defects he defibrillated the heart by electric shock. We were anxious to avoid, if possible, the use of such a potentially dangerous procedure in animals or patients, so we have used a fairly simple method.

This method consists of slipping a small plastic tube into the chamber of the left ventricle through a stab wound in the apex. The tube is connected to a source of mild suction. Contraction of the left ventricle then ejects any contained blood or air into this tube instead of into the aorta. The blood removed is returned to the extracorporeal circuit. Subsequently, after the operative procedure within the heart is completed, the tube can be quite simply withdrawn. We think it is important, when employing an open cardiectomy for the closure of septal defects, to have some method of being sure that air embolism will not occur in the systemic arteries.

DR. HELMSWORTH (Closing).—In answer to the question Dr. Dennis raised, of course, we cannot be certain. In the examination of dogs that have died after the experiment, very careful attention is given to the coronary vessels as well as the cerebral vessels; we feel that in the largest number of instances of oxygen embolization we can see collections of gas in those vessels. This finding is a very infrequent one at necropsy on animals in the most recent group of experiments.

VARIATIONS IN THE BRONCHOVASCULAR PATTERNS OF THE LEFT LOWER LOBE OF FIFTY LUNGS

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THIS article represents the last of a series of studies analyzing the variations in gross structure of the bronchopulmonary segments of adult human lungs. Emphasis will be placed on the patterns assumed by the pulmonary arteries and veins of the left lower lobe. Yet because the patterns are largely determined by the arrangement of bronchi it has also been necessary to identify the bronchial variations in these fifty specimens. These, added to the ones described by Berg and Boyden in 1949, provide us with an incidence of variation based on 110 specimens.†

THE GENERAL VENOUS PATTERN

The left lower lobe is drained almost exclusively by the left inferior pulmonary vein. This is in marked contrast to the situation described by Boyden and Scannell in the right lung where the region of fusion of superior segment and upper lobe is partially drained by the posterior vein of the upper lobe in 54 per cent of specimens. A comparable arrangement (Fig. 2, B) was found in only 6 per cent of left lungs (Boyden and Hartmann, 1946). Presumably this is due to the fact that the left superior segment is rarely fused to the upper lobe, congenitally.

The prevailing pattern of the veins in the left lower lobe is illustrated in Plate 1. To expose the branches of the inferior pulmonary vein by dissection, a small vein is located in the hilum (V^7b) which runs beneath the pulmonary ligament (cf. Plate 2, left figure). This vein leads into the cleavage plane which separates the medial basal (B^7) from the posterior basal segment (B^{10}). After B^7 is reflected laterally, the big veins are encountered (right figure, Plate 2). These vessels fit snugly against the basal bronchi. In Plate 1 the inferior pulmonary has been retracted medially to show better the relationship of veins to bronchi.

In general, the venous pattern resembles that of the right lower lobe. The left pulmonary vein receives two main tributaries— V^6 , which drains the superior segment (cf. Plate 3), and the common basal vein. The latter receives

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two main tributaries—the superior basal (S) and the inferior basal (I).^{*} These, in turn, receive the segmental and intersegmental veins.[†] However, there is one striking difference between the veins of the two lower lobes. On the right, the superior basal vein is more commonly formed by V^8 and V^9 , and the inferior basal by V^{10} . On the left, the reverse is true: V^9 and V^{10} more commonly unite to form the inferior basal (Table I). Also, the common trunk of V^9 and V^{10} is shorter (Plate 1), so that occasionally V^9 —or a subsuperior vein which is usually tributary to it, $VX^*(10)$ —forms the middle member of a trifurcation (Table I). Then we may recognize a common basal vein which is formed by three major trunks—a superior basal, a posterior basal, and an inferior basal vein (cf. Plate 4, #12). Such an arrangement has not been observed in the right lower lobe.

In constructing Table I, small tributaries of the basal veins such as V^7 , or the usually small $VX^*(9)$ and $VX^*(10)$, etc., have been omitted. Yet, it has been necessary to recognize "split" types, as in the right lower lobe. Thus, in 18 per cent of our 50 specimens, V^{10} , V^9 , or V^8 is represented by two veins, one of which joins the superior basal vein, the other of which joins the inferior basal vein. In the right lower lobe this occurred in 62 per cent of 50 specimens.

TABLE I. PATTERN OF BASAL VEINS

	SUP. BASAL	POST. BASAL	INF. BASAL	PERCENTAGE
Bifurcations				94%
Uncomplicated types	V^8 $V^8 + 9$		$V^9 + 10$ V^{10}	41% 32%
"Split" types	$V^8 + 9$ $V^8, 9, 10$ V^8		$V^9 + 10$ V^{10} $V^8, 9, 10$	4% 8% 6%
Trifurcations	V^8 $V^8 + 9$	V^9 VX^*	V^{10} V^{10}	2% 4%

Last, displaced lingular veins occurred in only five specimens (10 per cent). Four of these emptied into the inferior pulmonary vein (two being associated with V^7), and one into the superior basal. (Boyden and Hartmann found the same percentage of displaced lingular veins.) In general, it is clear that the left inferior pulmonary vein is much less variable in its mode of formation than the right inferior pulmonary. (See Table III of Ferry and Boyden.)

Of special interest is the specimen illustrated in Fig. 3. This is the only case in which the basal veins appeared to cross the anterior surface of the lobe superficially. This is due to the fact that B^7 arises as a displaced ramus (BX^7) of the lateral basal bronchus (B^9).

THE SUPERIOR SEGMENT (B^6)

1. *New Observations on the Bronchial Pattern.*—Before discussing the blood supply of the segment we shall briefly review the bronchial pattern of the segment and then present new observations on its variability.

^{*}For discussion of terminology, see Ferry and Boyden, 1951

[†]According to the system devised by Boyden in 1945, the vein which lies on the clockwise side of a given left bronchus (as viewed from in front) receives the same number as that bronchus (cf. Plate 1).

TABLE II. SUMMARY OF SUPERIOR SEGMENTAL BRONCHUS (B^s)

	PITEL AND BOYDEN (50 SPEC.)	BERG AND BOYDEN (60 SPEC.)	TOTAL (110 SPEC.)
I. B^s arises as a single trunk			83.7%
1. B^s bifurcates into			
1) B^{sa} and $B^{sb} + c$	42%	43%	42.7%
2) B^{sb} and $B^{sa} - c$	32%	27%	29.1%
3) B^{sc} and $B^{sa} - b$	2%	10%	6.4%
4) Bizarre patterns (split B^{sb})	6%	5%	5.5%
2. B^s trifurcates into			15.4%
1) B^{sa} ; B^{sb} ; B^{sc}	14%	15%	14.5%
2) B^{sa1} ; $B^{sa2} - c$; B^{sb}	2%	0%	0.9%
II. B^s arises as two separate trunks			0.9%
$B^{sb} - c$ and B^{sa} (Plate 4, $\frac{2}{7}$)	2%	0%	

The superior or "apical" bronchus of the left lower lobe has three main branches: a medial ramus (B^{sa}), a superior ramus (B^{sb}), and a lateral ramus (B^{sc}). The present study confirms the observation of Berg and Boyden that the most common pattern (43 per cent) is a bifurcation having the formula " B^{sa} and $B^{sb} + c$ " (cf. Table II and Plate 5). By virtue of the fact that B^{sa} extends downward along the paravertebral surface toward the diaphragm (Table III), the left superior segment caps the lower lobe obliquely, whereas on the right side it is prevaillingly horizontal. This distinction is best shown in colored plates of injected specimens (1949 articles) and explains why resection of the superior segment can be more difficult on the left side.

TABLE III. LOWEST EXTENT OF MEDIAL RAMUS (B^{sa}) ON THE PARAVERTEBRAL SURFACE

	PITEL AND BOYDEN (50 SPEC.)	BERG AND BOYDEN (60 SPEC.)	TOTAL (110 SPEC.)
Extends two-thirds or more of distance to diaphragm	38%	57%	48.2%
Half-way to diaphragm	46%	37%	40.9%
One-third of distance to diaphragm	10%	3%	6.4%
Fails to reach paravertebral surface*	6%	3%	4.5%

*In 12% of the 110 specimens the upper portion of the paravertebral surface is supplied by an accessory branch of B^{sb} , which is then designated BX^{sa1} . In 4.5% the accessory branch replaces B^{sa1} ; in the remaining 7.5% it supplements B^{sa1} .

In the present series of specimens we have encountered a new complication—namely the displacement of B^{sa} to a position on the basal bronchus 14 mm. below the main orifice of B^s (see Specimen $\frac{2}{7}$, Fig. 1). That this displaced ramus is not a medial subsuperior bronchus (B^*)—as one might first surmise—is made clear by a comparison of Specimens $\frac{2}{7}$ and $\frac{12}{12}$ in Plate 4. In $\frac{12}{12}$, B^{sa} (with its superficial and deep branches, B^{sa1} and B^{sa2}) is obviously the medial ramus of a bifurcating B^s . In $\frac{2}{7}$, the bronchus with branches labeled B^{sa2} and B^{sa1} distributes to virtually the same territory. Therefore, it represents a displaced B^{sa} . Also, as in $\frac{12}{12}$, its artery (AX^{sa}) arises atypically from A^{10} , but at the same level as the displaced artery to the lateral ramus, namely AX^{sc} .

This finding of two orifices for the left superior segment is unique in our experience. On the right side such an arrangement has been noted in 6 per

cent of 100 specimens (Table II of Ferry and Boyden). On that side, however, the lower orifice represents ramus B^c (see Fig. 1 of these authors).

In the present study of the left lobe we have also encountered, for the first time, two instances of a subsuperior bronchus (B^*) which supplies the paravertebral surface. Previously Neil and his co-workers had mentioned that such a medial stem existed on the left side. An example of this is now shown in Plates 2 and 3. In the left-hand figure of Plate 2, B^* occupies a paravertebral position. Why, then, should it not be interpreted as a displaced B^a ? The first reason is that a B^a is already present in its usual place. Second, only a portion of B^* supplies the superficial paravertebral surface. Most of it extends posteriorly (see truncated lobe on right side of Plate 2). It is interesting to note, however, that since its orifice is only 12 mm. below the orifice of B^c , the bronchoscopist would not be able to distinguish between a medial subsuperior and an inferomedially displaced second orifice of B^c .

The question will also be raised as to why a high, *laterally* directed subsuperior, which frequently supplies the anterior surface below a high B^c , should not be interpreted as an inferiorly displaced B^c , especially since this is the form of duplication that occurs in the right superior segment. In answering this, attention is called to the deceptive specimen presented in Plate 5. Twelve millimeters below the keel of B^c , there arises a B^* with deep branches passing to the posterolateral surface and superficial branches supplying the anterior surface. In the absence of B^a , the superficial ramus is interpreted as a displaced B^a (BX^a from B^*). But inferior to these superficial branches is a vein (here labeled VX^a) which empties into the superior vein (V^c). Since the bronchus in question is cut off by a branch of the superior vein, why should this bronchus not be identified as a displaced B^c ? The answer is that it is too low, also that this is the direction which the subsuperior bronchus usually assumes on the left side (see footnote, Table VII). Therefore it is a subsuperior bronchus carrying certain anterior basal branches.

With this introduction, we may now proceed to consideration of the arrangement of blood vessels in the superior segment.

2. *The Arteries of the Superior Segment* (A^c).—In a previous analysis of the left upper lobe it has been noted that the left pulmonary artery crosses the bronchus of the left upper lobe to enter the floor of the interlobar fissure. As it makes the turn it gives off a varying number of superior and posterior arteries to the superior division segments of the upper lobe (Fig. 2). Somewhat below these, on its medial side, appears a cluster of arteries to the lingular segments ($A^{c,s}$, Fig. 2, *B*). Unexpectedly, the first artery to the lower lobe arises between these two groups (A^c , Fig. 2), that is, above some of the arteries of the upper lobe. For this reason, Kent and Blades early pointed out the necessity of ligating the arteries individually in lobectomies of either the left upper or lower lobes. Even when there are two separate arteries to the superior segment ($A^a + b$ and A^c , Fig. 2, *C*) this relationship still holds, as a rule. In this respect, therefore, the left pulmonary artery differs in its mode of branching from the artery of the right lung. For on that side, when there are two or more arteries to the superior segment, the lower one usually arises below the middle

lobe artery—or the second middle artery, if there are two. (See Fig. 3 of Boyden and Hamre.)

As indicated in Table IV, the left superior segment was found to be supplied by two arteries in about one-third of our fifty specimens. The incidence of this variation is thus twice as great as in the right superior segment (16 per cent, Ferry and Boyden). Furthermore, the complex types of branching are somewhat more numerous on the left—28 per cent (Table IV) as against 24 per cent on the right.

TABLE IV. ARTERIAL SUPPLY OF SUPERIOR SEGMENT

I. Segment supplied by single artery bifurcating into		64%
1. Simple types	48%	
1) A^sa and $A^sb - c$	22%	
2) A^sb and $A^sa - c$	24%	
3) A^sc and $A^sa - b$	2%	
2. Complex types (with displaced branches)	16%	
II. Segment supplied by two separate arteries		34%
1. Simple types	22%	
1) A^sa and $A^sb - c$	12%	
2) A^sb and $A^sa - c$	4%	
3) A^sc and $A^sa - b$	6%	
2. Complex types (with displaced branches)*	12%	
III. Segment supplied by three separate arteries (One of the three, A^{sa} , came from A^{11})		2%

*In 5 of the 5 specimens, A^{sa1} (or A^{sa2}) arose atypically from A^{11} .

Of special interest are the 12 per cent of specimens in which A^sa , or one of its two branches, arises from a displaced position on A^{11} , the artery to the posterior basal segment (cf. A^{sa2} , Plate 5; A^{sa} , Plate 4). Such an arrangement was never found in the right lower lobe. Also, in 14 per cent, A^{sa1} arose as a displaced branch of A^sb (cf. A^{sa1} , Plate 2). These aberrations are presumably correlated with the greater paravertebral extent of B^sa in the left lung. In view of these variations, we were surprised to find that the arterial pattern corresponds to the bronchial pattern more frequently in the left superior segment than in the right. For in only 36 per cent do the arteries cross the subsegmental planes, whereas on the right side the arteries fail to reproduce the bronchial pattern in 44 per cent of specimens. Nevertheless, it would seem that resection of subsegmental portions of the superior segments would be somewhat hazardous. This is accentuated by the variability of the veins.

3. The Veins of the Superior Segment (V^s).—With few exceptions the veins of the superior segment drain into a large trunk (V^s) which lies on the median side of the left upper lobe bronchus (Plate 1). As it swings around from behind the upper lobe bronchus, it varies in the depth of its position. Prevaillingly (56 per cent), it emerges from the deep side of B^sa (Plate 5). In another 30 per cent, V^s or its main branch passes superficially to B^sa (Specimen #12, Plate 4); and in the remaining 14 per cent of specimens it courses between the two branches of B^sa (Plate 2).

cent of 100 specimens (Table II of Ferry and Boyden). On that side, however, the lower orifice represents ramus B^c (see Fig. 1 of these authors).

In the present study of the left lobe we have also encountered, for the first time, two instances of a subsuperior bronchus (B^*) which supplies the paravertebral surface. Previously Neil and his co-workers had mentioned that such a medial stem existed on the left side. An example of this is now shown in Plates 2 and 3. In the left-hand figure of Plate 2, B^* occupies a paravertebral position. Why, then, should it not be interpreted as a displaced B^a ? The first reason is that a B^a is already present in its usual place. Second, only a portion of B^* supplies the superficial paravertebral surface. Most of it extends posteriorly (see truncated lobe on right side of Plate 2). It is interesting to note, however, that since its orifice is only 12 mm. below the orifice of B^c , the bronchoscopist would not be able to distinguish between a medial subsuperior and an inferomedially displaced second orifice of B^c .

The question will also be raised as to why a high, *laterally* directed subsuperior, which frequently supplies the anterior surface below a high B^c , should not be interpreted as an inferiorly displaced B^c , especially since this is the form of duplication that occurs in the right superior segment. In answering this, attention is called to the deceptive specimen presented in Plate 5. Twelve millimeters below the keel of B^c , there arises a B^* with deep branches passing to the posterolateral surface and superficial branches supplying the anterior surface. In the absence of B^a , the superficial ramus is interpreted as a displaced B^a (BX^a from B^*). But inferior to these superficial branches is a vein (here labeled VX^a) which empties into the superior vein (V^c). Since the bronchus in question is cut off by a branch of the superior vein, why should this bronchus not be identified as a displaced B^c ? The answer is that it is too low, also that this is the direction which the subsuperior bronchus usually assumes on the left side (see footnote, Table VII). Therefore it is a subsuperior bronchus carrying certain anterior basal branches.

With this introduction, we may now proceed to consideration of the arrangement of blood vessels in the superior segment.

2. *The Arteries of the Superior Segment (A^c).*—In a previous analysis of the left upper lobe it has been noted that the left pulmonary artery crosses the bronchus of the left upper lobe to enter the floor of the interlobar fissure. As it makes the turn it gives off a varying number of superior and posterior arteries to the superior division segments of the upper lobe (Fig. 2). Somewhat below these, on its medial side, appears a cluster of arteries to the lingular segments (A^4 , Fig. 2, *B*). Unexpectedly, the first artery to the lower lobe arises between these two groups (A^c , Fig. 2), that is, above some of the arteries of the upper lobe. For this reason, Kent and Blades early pointed out the necessity of ligating the arteries individually in lobectomies of either the left upper or lower lobes. Even when there are two separate arteries to the superior segment ($A^a + b$ and A^c , Fig. 2, *C*) this relationship still holds, as a rule. In this respect, therefore, the left pulmonary artery differs in its mode of branching from the artery of the right lung. For on that side, when there are two or more arteries to the superior segment, the lower one usually arises below the middle

lobe artery—or the second middle artery, if there are two. (See Fig. 3 of Boyden and Hamre.)

As indicated in Table IV, the left superior segment was found to be supplied by two arteries in about one-third of our fifty specimens. The incidence of this variation is thus twice as great as in the right superior segment (16 per cent, Ferry and Boyden). Furthermore, the complex types of branching are somewhat more numerous on the left—28 per cent (Table IV) as against 24 per cent on the right.

TABLE IV. ARTERIAL SUPPLY OF SUPERIOR SEGMENT

I. Segment supplied by single artery bifurcating into		64%
1. Simple types	48%	
1) A ^a a and A ^b b - c	22%	
2) A ^b b and A ^a a - c	24%	
3) A ^c c and A ^a a - b	2%	
2. Complex types (with displaced branches)	16%	
II. Segment supplied by two separate arteries		34%
1. Simple types	22%	
1) A ^a a and A ^b b - c	12%	
2) A ^b b and A ^a a - c	4%	
3) A ^c c and A ^a a - b	6%	
2. Complex types (with displaced branches)*	12%	
III. Segment supplied by three separate arteries (One of the three, A ^a a, came from A ¹⁰)		2%

*In 5 of the 6 specimens, A^aa1 (or A^aa2) arose atypically from A^a.

Of special interest are the 12 per cent of specimens in which A^aa, or one of its two branches, arises from a displaced position on A¹⁰, the artery to the posterior basal segment (cf. AX^aa2, Plate 5; AX^aa, Plate 4). Such an arrangement was never found in the right lower lobe. Also, in 14 per cent, A^aa1 arose as a displaced branch of A^bb (cf. AX^aa1, Plate 2). These aberrations are presumably correlated with the greater paravertebral extent of B^aa in the left lung. In view of these variations, we were surprised to find that the arterial pattern corresponds to the bronchial pattern more frequently in the left superior segment than in the right. For in only 36 per cent do the arteries cross the subsegmental planes, whereas on the right side the arteries fail to reproduce the bronchial pattern in 44 per cent of specimens. Nevertheless, it would seem that resection of subsegmental portions of the superior segments would be somewhat hazardous. This is accentuated by the variability of the veins.

3. *The Veins of the Superior Segment (V^a).*—With few exceptions the veins of the superior segment drain into a large trunk (V^a) which lies on the median side of the left upper lobe bronchus (Plate 1). As it swings around from behind the upper lobe bronchus, it varies in the depth of its position. Prevaillingly (56 per cent), it emerges from the deep side of B^aa (Plate 5). In another 30 per cent, V^a or its main branch passes superficially to B^aa (Specimen #12, Plate 4); and in the remaining 14 per cent of specimens it courses between the two branches of B^aa (Plate 2).

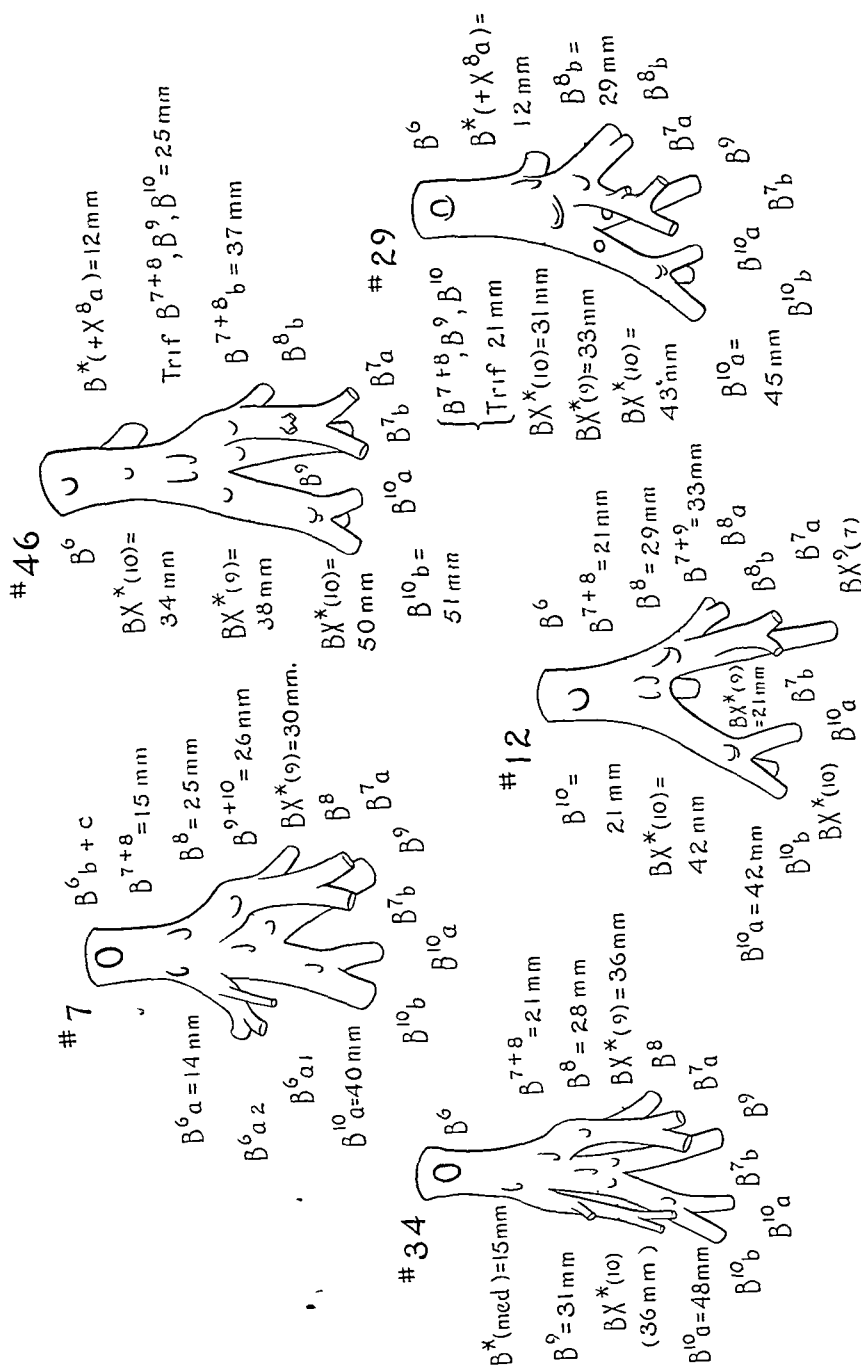


Fig 1.—Bronchial trees of specimens of left lower lobe selected to illustrate certain variations. The trees are drawn as if transparent in order to show position of keels. Distances are measured from the orifice (keel) of *Specimen* #7 (cf Plate 1), illustrating only case of double origin of the left superior bronchus (B^6) *Specimen* #12 (cf Plate 5), illustrating common form of trifurcation. *Specimen* #34, illustrating one of two specimens having a medial (paracardial) subapical bronchus (B^*). *Specimen* #12 (cf Plate 4), illustrating rare type of trifurcation into B^6 , B^{10} , B^{10} , and B^7 , *Specimen* #29, illustrating laterally placed subapical bronchus (B^*) invading the anterior basal segment (cf Plate 5).

Usually V^6 has three principal tributaries. Of these, the middle one (V^6b) is somewhat vertically oriented and emerges from the depths of the segment. This relationship is well shown in Plate 3 (see large unlabeled branch of V^6 that lies parallel and just inferior to B^6b). The other two, V^6a and V^6c , are usually intersegmental veins which separate the superior segment from adjacent zones. Commonly these are horizontally placed. In Plate 3, for instance, V^6a2 separates the superior segment from the subsuperior zone (see bronchus associated with A^*). In Plate 2 the same vein (of the same specimen) is seen on the bottom of the upturned superior segment. On the lateral side, the vein which separates the superior from the anterior basal segment, or its displaced lateral branch (BX^3a), is V^6c . This is well shown in Specimen #7 (Plate 4) and in Plate 5. However, these intersegmental veins are not always present. In 10 per cent there is no large V^6a branch but only scattered venous twigs, and in another 10 per cent V^6c is wholly or virtually absent (Plate 2).

The mode of branching is also variable. In fact the vein often exhibits a shrublike appearance, so that in analyzing its pattern one has to deal with just the major tributaries. The prevailing patterns have the formula V^6b and $V^6a + c$ (36 per cent) or V^6a and $V^6b + c$ (32 per cent). In another 12 per cent there was a "splitting" of V^6a or V^6b —that is, one or the other of these rami were represented by two large branches widely separated from each other. In another 20 per cent (as noted earlier) either V^6a or V^6c were defective. In the remaining 2 per cent the vein was formed by the two tributaries V^6c and $V^6a + b$.

Because of these variations the mode of branching of V^6 was observed to follow the bronchial pattern in only 22 per cent of specimens. Finally, in a comparison of the venous drainage of the left and right superior segments, the principal difference would be found in the greater development of V^6a in the left lung. This may be correlated with the greater prominence of B^6a on the left side. It will be recalled that the major ramus of the right segment is B^6c , and that in 60 per cent of right superior segments V^6 was formed by only two major tributaries— V^6b and V^6c .

THE BASAL SEGMENTS

1. *General Mode of Division of Basal Bronchi and Arteries.*—After the lower lobe bronchus gives off the dorsal branch that supplies the superior segment (B^6), it continues as an undivided trunk for an average distance of 17 mm. We have named this portion of the bronchial tree the "basal trunk" (Fig. 3).^{*} In nearly four-fifths of the lobes, this trunk divides into two stems—commonly $B^7 + 8$ and $B^9 + 10$ (62 per cent of 110 specimens). In the remaining fifth it branches into three stems (Table V).

The corresponding portion of the left pulmonary artery—the "basal artery"—has the following patterns: in 42 per cent it divides into $A^7 + 8$ and $A^9 + 10$ (cf. Fig. 2, A), and in 4 per cent it trifurcates (cf. Plate 4, #7)†; but

^{*}Its range in length is from 8 to 27 mm with peaks at 15 and 20 mm. In defining this shoot (B^6) which occurs in 14 per cent of 50 specimens (cf. Plate 2, middle figure).

†In this classification the numerous and variable arteries to the subsuperior segments (A^4) have been disregarded (cf. Fig. 2, B). These will be discussed later.

TABLE V. MODE OF BRANCHING OF BASAL TRUNK†

	PITEL AND BOYDEN (50 SPEC.)	BERG AND BOYDEN (60 SPEC.)	TOTAL (110 SPEC.)
I. Basal trunk bifurcates			77.3%
1. Into $B^7 + s$ and $B^9 + 10†$	56%	66.7%	61.8%
2. Into bizarre patterns	10%	20.0%	15.5%
1) $B^7 + sa$ and $B^9b + B^{10}$ (B^9 absent)	0%	1.7%	0.9%
2) B^7 and rest	4%	10.0%	7.3%
3) B^8 and rest	0%	1.6%	0.9%
4) B^{10} and rest	6%	6.7%	6.4%
II. Basal trunk trifurcates			22.7%
1. Into $B^7 + s$; B^9 ; B^{10}	30%	13.3%	20.9%
2. Into $B^8 + B^7 + s$; BX^* (9); B^{10} } or $B^7 + s$; BX^* (9); $B^{10} + s$ }	4%	0.0%	1.8%

†For details of variation within a given stem, such as those for $B^7 + s$, $B^7 + 10$, and so forth, see following tables.

in the remaining 54 per cent it divides very unevenly—into A^{10} and the rest (46 per cent, cf. Fig. 2, C), A^8 and the rest (6 per cent, cf. Fig. 2, B), or A^{10b} and the rest (2 per cent).

The peculiar grouping together of arteries 7, 8, and 9 (46 per cent) may be explained largely by peculiarities of the bronchial pattern in these specimens—namely by the displacement of B^9 to a position on B^7 (8 per cent, cf. BX^9 , Fig. 1, #12 and Plate 4, B), by the trifurcation of the basal bronchus (28 per cent, cf. #46, Fig. 1), or by the shortness (3 to 7 mm.) of the common

TABLE VI. THE MEDIAL BASAL BRONCHUS (B^7)

	PITEL AND BOYDEN (50 SPEC.)	BERG AND BOYDEN (60 SPEC.)	TOTAL (110 SPEC.)
I. Origin of B^7			
1. Arises in common with B^8 (or ramus)	96%	86.6%	90.9%
1) B^7 lies anterior to B^8	66%	47%	55.5%
2) B^7 lies in same plane as B^8	30%	35%	32.7%
3) B^7 lies deep to B^8	0%	5%	2.7%
2. Arises separately from basal trunk	4%	10%	7.3%
3. Absent as such (displaced to B^9)	0%	3%	1.8%
II. Distribution of B^7			
1. Supplies whole width* of anterior surface	28%	61.7%	46.4%
2. Supplies medial half or third of anterior surface	36%	21.7%	28.2%
3. Supplies anterior and sector of costal surface	36%	10.0%	21.8%
4. Supplies one half of anterior surface (one ramus absent)	0%	3.3%	1.8%
5. Absent as such	0%	3.3%	1.8%
III. Occurrence of large diaphragmatic ramus (B^{7c})			
1. Arises as branch of B^{7b}	26%		
2. Arises as branch of B^{7a}	16%		
3. Arises from common trunk of B^7	16%		
4. Arises from B^9 (as BX^{7c})	2%		
5. Represented by small branches	40%		

*As measured along inferior margin from pulmonary ligament to lateral margin of lobe.

trunk of B^2 and B^{10} (8 per cent, cf. Plate 5). This accounts for the pattern in eighteen of the twenty-two specimens in which A^7 , A^8 , and A^9 have a common stem. Nevertheless, the fact remains that in two-thirds of all specimens the basal artery has a different mode of branching than the associated basal bronchus.

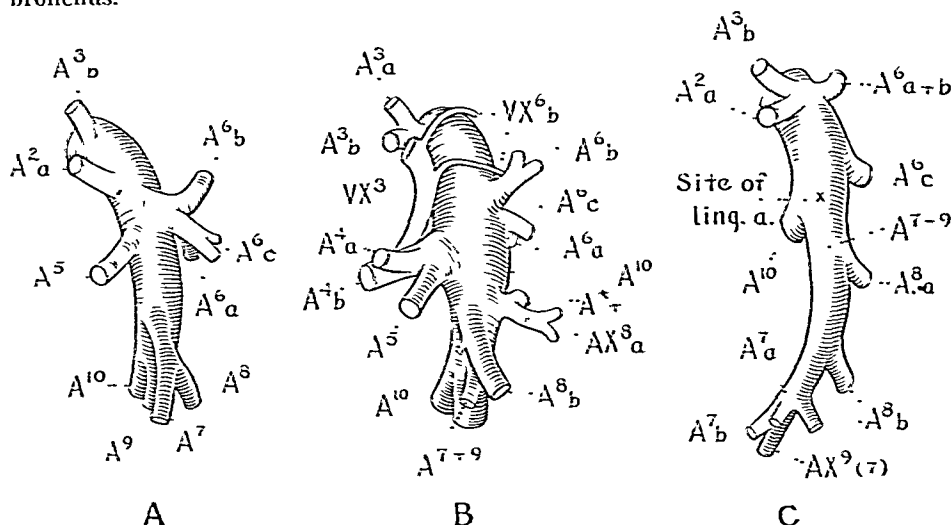


FIG. 2.—Sketches of the interlobar portion of the left pulmonary artery to illustrate relation of arteries of the superior segment (A^1) to the lingular arteries of the upper lobe (A^2 and A^3). Specimen A, illustrating single A^1 at level between artery to the anterior segment (A^2a) and A^2b . The basal artery divides conventionally into A^1b and A^1c . Specimen B, illustrating two superior segmental arteries lying above level of A^1 and A^2 , also atypical division of basal artery into A^1b and A^1c . Specimen C, illustrating absence of lingular arteries on interlobar portion of pulmonary artery and the prevailing pattern of division of basal artery into A^1b and A^1c .

2. The Medial Basal Segment (B^2).—

The bronchial pattern: As summarized in Table VI, the medial basal bronchus has the following characteristics. It arises in common with B^3 (or one of its rami) in approximately 91 per cent of 110 specimens (cf. Plate 1).^{*} In 7 per cent it arises independently from the medial portion of the basal trunk, as does its homologue of the right lower lobe (see Fig. 5 of Berg and Boyden). In 2 per cent it is absent as such (see Fig. 3). It distributes prevalingly (in 46 per cent) to the whole width of the anterior surface of the base of the lobe (Plate 5), or (in 30 per cent) it may supply less than that (Plate 4, =7), or (in 22 per cent) it may even extend onto the costal surface (Plate 4, C).

The diaphragmatic surface of the segment is supplied prevalingly (in 40 per cent) by small branches of B^2a and B^2b , or (in 42 per cent) by a large branch of either B^2a or B^2b , or (in 16 per cent) by a single large stem (B^2c) which arises from the main trunk of B^2 , before the latter divides into the usual medial and lateral rami (cf. Fig. 3). A discussion of the reasons why the medial basal bronchus should be considered to have the status of at least a subsegmental bronchus (and perhaps a segmental one) may be found in the article by Boyden, 1953.

^{*}The average length of this common trunk in 25 specimens is 8.5 millimeters.

The arterial pattern: Since B^7 arises in common with B^8 or one of its branches, in 91 per cent of specimens, it would be expected that A^7 would usually have a common origin with A^8 or one of its branches, and such is the case in all but 8 per cent of fifty specimens (cf. Plate 4, #12). Similarly, since B^7 at its point of origin lies in a plane superficial to B^8 (66 per cent of fifty specimens) one would assume that A^7 would cross in front of B^8 in the majority

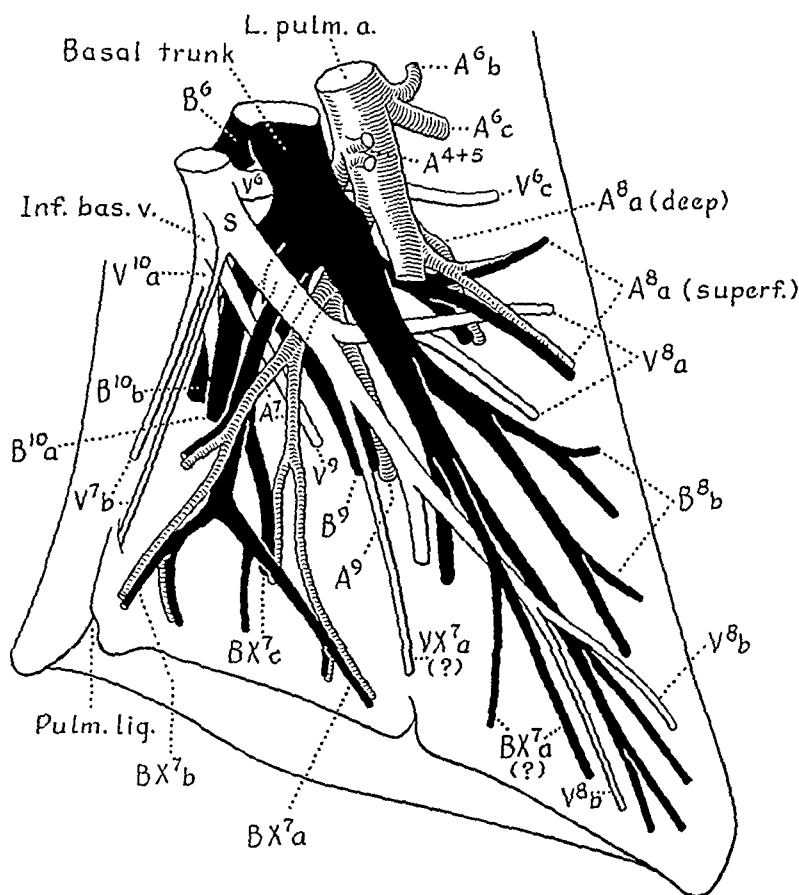


Fig. 3.—Sketch of dissected anterior surface of left lower lobe of a unique specimen. (Dissection by S. H. Robinow.) Superior basal vein passes anterior to all bronchi except B^6 . B^7 (the medial basal) is absent as such and originates as a displaced bronchus (BX^7) from the proximal portion of the lateral basal bronchus (B^8). The basal trunk trifurcates into B^6 , B^7 , and B^{10} . Note high position of A^8 above level of lingular arteries (A^{4+5}). The A^6 branch is hidden behind A^6b . The territory supplied by BX^7 is narrower than usual, and some of the branches of B^8 have invaded its territory (BX^7a).

of specimens, and such is the case (cf. Plate 4, #7). However, in 26 per cent, A^7 passes deep to the anterior basal bronchus. Such specimens are dangerous from the standpoint of resection of segments, for in about one-half of these specimens the artery to the lateral basal segment (A^9) arises anomalously from the deep side of A^7 . In such lobes the ligation of a supposedly single artery could well occlude two segmental arteries instead of the anticipated one. An example of a displaced artery (AX^9), arising from the deep side of A^7b , is shown in Fig. 2, C (AX^9 from ?).

The venous pattern: The veins of the medial basal segment are small vessels ranging in number from one to four, and occasionally there are more. Typically, there are two (36 per cent of specimens). The first of these (V^7a) runs between the two rami of the segment (Plate 5) and empties, in two-thirds of the specimens, into V^7b —the intersegmental vein which separates the medial basal from the lateral basal segment (Plate 5). However, it may drain into the common basal, the superior basal, or even the inferior basal or one of its branches (V^9 , Plate 2, right figure).

The second vein, V^7b (Plate 4, $\equiv 7$), is the intersegmental vein which separates the medial basal from the posterior basal segment (B^{10}). This is the vein which usually lies deep to the pulmonary ligament (Plate 2, left figure) and leads into the cleavage plane which separates the shallow medial basal segment from the underlying segments, B^{10} and B^9 . Typically, V^7b drains into the common basal vein (Plate 4, $\equiv 7$), but almost as frequently into the inferior basal (Plate 2, right figure). Atypically, it discharges into the superior basal vein or one of its branches.

When there are more than two veins draining the segment (44 per cent) there may be two V^7as and one V^7b , or vice versa, or two of each. The remaining 20 per cent of specimens are characterized by the presence of a single V^7 having a and b rami. This may be the only vein, or it may be supplemented by a second vein, V^7a or V^7b . On its deep side the medial basal segment is usually separated from the lateral basal segment by tributaries of V^9 (Plate 2, right figure). Thus in resecting the medial basal segment lateralward, one could enter the pulmonary ligament to V^7b , thence along the tributaries of V^9 , and thence to V^{9b} , the vein which separates the medial basal from the anterior basal segment.

3. The Anterior Basal Segment (B^8).—

The bronchial pattern: In contrast to the median basal bronchus with which it is so frequently associated, the anterior basal bronchus is a highly variable and frequently defective stem, both in its mode of branching and in its distribution. As summarized in Table VII, one or the other of its two rami was missing in 17 per cent of 110 specimens. The territory normally supplied by its lateral ramus (B^8a , Plate 2) is either invaded by neighboring bronchi (cf. Plate 4, $\equiv 7$) or wholly supplied by others (Plate 5) in 35 per cent of specimens. Its basal ramus, which normally reaches the diaphragmatic surface of the lobe (B^8b , Plate 4, $\equiv 7$), fails to reach the base of the lung in 19 per cent of specimens (cf. Plate 4, C). In the present study we have become aware of the frequency of another variation in the mode of branching of the anteromedial basal trunk—namely, the high origin of B^8a on the common stem of B^{7+8} . As a result, the trunk divides unevenly into B^8a and B^{7+8b} . This was observed in 24 per cent of fifty specimens (Plate 2, left figure). It is not surprising, therefore, that the arteries supplying the segment should have a complicated pattern.

The arterial pattern: The artery to the anterior basal segment arises separately from the basal artery in only three cases (6 per cent of fifty specimens). In two of these A^8 arises high up on the basal artery. Lower down the latter then divides into A^7 and A^{7+10} , or A^{7+9} , A^{10a} , and A^{10b} . In the third case

TABLE VII. THE ANTERIOR BASAL BRONCHUS (*B^a*)

	PITEL AND BOYDEN (50 SPEC.)	BLRG AND BOYDEN (60 SPEC.)	TOTAL (110 SPEC.)
I. Origin of <i>B^s</i>			
1. Arises wholly or in part with <i>B⁷</i>	96%	86.6%	90.9%
1) <i>B^s</i> has typical pattern (Plate 1)	56%	65.0%	61.0%
2) <i>B^{sa}</i> arises higher, <i>B⁷ + sb</i> lower, on stem	18%*	8.3%	12.7%
3) <i>B^{sa}</i> absent (stem consists of <i>B⁷ + sb</i>)	16%†	8.3%	11.8%
<i>B^{sa}</i> replaced by ramus of <i>BX[*]</i> (9),	8%		
<i>B^{sa}</i> replaced by ramus of <i>B[*]</i> ,	6%		
<i>B^{sa}</i> replaced by ramus of <i>B^a</i> ,	2%		
4) <i>B^s</i> carries displaced <i>B^a</i> (In 2%, <i>B^{sa}</i> arises high on stem)	6%	1.7%	3.6%
(In 2%, <i>B^{sa}</i> replaced by <i>B[*]</i>)			
5) <i>B^{sb}</i> absent (stem consists of <i>B⁷ + sa</i>)	0%	3.3%	1.8%
(<i>B^{sb}</i> replaced by ramus of <i>B^a</i>)			
2. <i>B^s</i> arises alone from basal trunk	1%	13.4%	9.1%
II. Distribution of <i>B^{sa}</i> and <i>B^{sb}</i>			
1. <i>B^{sa}</i> alone supplies upper half of segment			64.6%
2. <i>B^{sa}</i> assisted or replaced‡			35.4%
1) By <i>BX[*]</i> (9)	22%	13.3%	17.3%
2) By <i>B[*]</i>	18%	13.3%	15.4%
3) By <i>B^a</i>	2%	0.0%	0.9%
4) By <i>BX[*]</i> (10)	1%	0.0%	1.8%
	46%	26.6%	35.1%
3. <i>B^{sb}</i> reaches basal surface of lobe	78%	83.3%	80.9%
4. <i>B^{sb}</i> fails to reach basal surface	22%	16.7%	19.1%

*Total is 20% of 50 specimens (add line 16 of table, and cf. Plate 2)

†Total is 18% of 50 specimens (add line 18 of table, and cf. Plate 5)

‡*B^{sa}* assisted by other bronchi in 21.8% (cf. Plate 1), replaced by others in 13.6% of 110 specimens (cf. Plate 5).

A^{1a} was absent as such, and *A^{1b}* arose high up on the basal artery. Lower down the latter divided into *A¹⁰* and *A⁷ + A^a + AX^{*}* (9). In the remaining 94 per cent, *A^s* or its rami were branches of the anteromedial basal artery. Accordingly the patterns of *A^s* will be discussed in relation to the parent artery, *A^{7 + s}* (cf. Plate 4, #7).

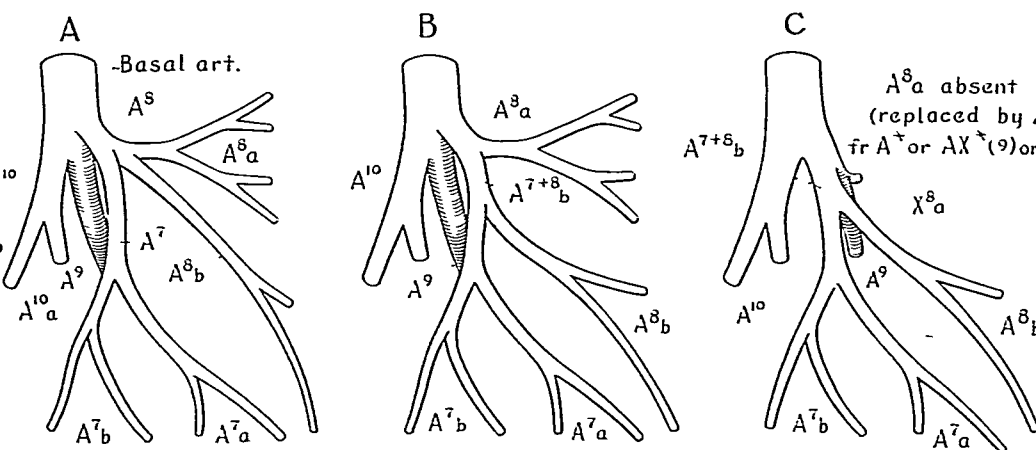
The three major patterns are shown in Fig. 4. Diagram 1 represents the prevailing type (20 per cent) in which the parent artery divides into *A⁷* and *A^a*.* The arrangement conforms to the bronchial pattern of the corresponding specimens in only 16 per cent of cases, yet 42 per cent of the bronchial trees have this conventional pattern.

In the second type (*B*, Fig. 4), *A^{1b}* arises separately as a branch of *A⁷* in 22 per cent of specimens. Rarely this type may have two *A^{1as}* (Plate 2, left

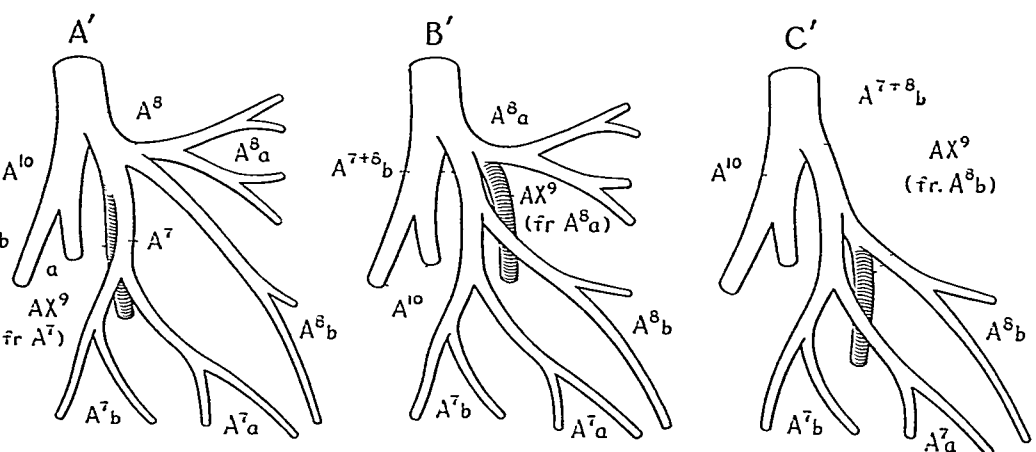
*In another 10 per cent of these specimens, *A¹⁰* arose higher up than is shown in the diagram and *A⁷* arose coordinately with *A^{7 + s}*.

figure). In only seven of these eleven specimens is the arterial pattern duplicated by the corresponding bronchi.

In the third type (C, Fig. 4) A^8a is absent as such in all five, and A^9 now arises coordinately with A^{7+8} . In each case the bronchial pattern is different.



0% (16% like bronchi) 22% (14% like bronchi) 10% (none like bronchi)



3% (none like bronchi) 4% (none like bronchi) 8% (none like bronchi)

Fig. 4—Diagram illustrating variations in pattern of the anteromedial basal artery (A^{8+9}). Diagram A shows the conventional pattern of arteries of the left lower lobe. In another 10 per cent A^{8+9} presents the same pattern but the artery arises collaterally with A^7 (coming on by itself). In diagram B, A^{8+9} arises separately from the common stem. In C, A^{8+9} is absent as such, and it originates as a displaced branch of A^7 which now arises collaterally with A^7 . In the lower row of figures, A^{8+9} has the same pattern as in the figure above it, but this time A^7 is displaced and originates from the deep side of the figure 1' (A^{8+9}), A^{8+9} (Fig. B'), or A^{8+9} (Fig. C'). In an additional specimen, A^{8+9} arose from the main stem of A^7 , making a total of 22 per cent in which A^{8+9} is displaced.

In the lower row of diagrams (A' , B' , C' , Fig. 4) similar arterial patterns are again shown, this time representing specimens complicated by displacement of the lateral basal artery (A^2) to a position on the deep side of A^7 , A^{8a} , or A^{8b} . In none of these does the arterial pattern conform to the bronchial plan. In addition to these ten there is another specimen in which A^2 is displaced to the main stem of A^8 . This makes a total of 22 per cent in which A^2 arises anomalously from the deep side of A^7 , A^8 , A^{8a} , or A^{8b} . Resection of the anteromedial basal segment in these specimens, therefore, could have jeopardized the blood supply of the lateral basal segment.

Finally it may be stated that only one-third of the anteromedial basal arteries (32 per cent) conform to the respective bronchial patterns.

TABLE VIII. THE LATERAL BASAL BRONCHUS (B^2)

	PITEL AND BOYDEN (50 SPEC.)	BERG AND BOYDEN (60 SPEC.)	TOTAL (110 SPEC.)
I. B^2 arises in conjunction with B^{10}	88%	90%	89.1%
1. From a trunk dividing into B^2 and B^{10}	54%*	66.7%	60.9%
2. Collaterally with B^{10} and $B^7 + s$	30%	13.3%	20.9%
3. From a common trunk, $B^8 -^{10}$	4%	10%	7.3%
II. B^2 absent as such (displaced)	12%	10%	10.9%
1. Replaced by ramus of B^7	2%	6.7%	4.6%
2. Replaced by ramus of $B^7 + s$	2%	0.0%	0.9%
3. Replaced by ramus of B^8	2%	0.0%	0.9%
4. Replaced by ramus of B^{8b}	2%	0.0%	0.9%
5. Replaced by ramus of B^{10a}	4%	1.7%	2.7%
6. Replaced by rami of B^7 , B^8 , B^{10}	0%	1.6%	0.9%
III. B^2 gives off high lateral branch, $BX^*(9)$	74%†	66.7%	70%

*To make this percentage conform to the 56% in Table V (Item I, 1), 2% must be taken from Item II, 5 of this table. The average length of this common trunk is 9 mm.

†In an additional 4%, $BX^*(9)$ is the middle limb of a trifurcation (cf. Fig. 1, #12, and Plate 4). In another 2% it is displaced onto B^{8a} .

4. The Lateral Basal Segment (B^2).—

The bronchial pattern: With the exception of B^8 , the lateral basal bronchus is the most variable of the basal bronchi, being absent as such in approximately 11 per cent of 110 specimens. Prevalingly, as summarized in Table VIII, it arises exclusively with B^{10} from a common stem $B^2 +^{10}$. This arrangement holds in three-fifths (60.9 per cent) of 110 specimens (cf. Plate 4, #7). In an additional three-tenths (28.2 per cent), it arises in conjunction with B^{10} but also with other bronchi. Soon after it is formed it gives off a high posterior lateral ramus, $BX^*(9)$, which contributes to the subsuperior zone (Table IX). This occurs in 70 per cent of 110 specimens. Its keel arises from 3 to 17 mm. below the keel of B^2 , at an average distance of 9.3 mm.

The arterial pattern: Since the lateral basal bronchus originates from a common trunk with B^{10} in three-fifths of fifty specimens, it would be expected that the arteries would have the same conventional arrangement, but such a pattern is realized in only 42 per cent (Fig. 2, A). The striking feature is the separate origin of A^{10} in 46 per cent of specimens, Fig. 4, B (and the occurrence of other variations in an additional 12 per cent). Accordingly A^2

TABLE IX. DISTRIBUTION OF BX* (9)

	PITEL AND BOYDEN (50 SPEC.)	BERG AND BOYDEN (60 SPEC.)	TOTAL (110 SPEC.)
I. Sector			
1. Posterolateral only	34%	40%	37.3%
2. Posterolateral and lateral	42%	14%	26.4%
3. Posterior and posterolateral	2%	8%	5.4%
4. Posterior, posterolateral, and lateral	2%	5%	3.6%
	80%	67%	72.7%
II. Angle made with anterior surface of lobe			
1. 40-60 degrees (posterolateral)	42%	45%	43.7%
2. 20-35 degrees (lateral)	36%	12%	22.7%
3. 70-90 degrees (posterior)	2%	10%	6.3%
	80%	67%	72.7%

must originate prevailingly with A^7 and A^3 , either as collateral branches of these and their rami (36 per cent) or as displaced branches of these (22 per cent, cf. Fig. 4, A' , B' , C'). The clinical importance of the latter, from the standpoint of resection of the anteromedial basal segment, has already been pointed out.

The venous pattern: The intersegmental vein (V^2), which lies on the clockwise side of B^2 , separates the lateral basal from the posterior basal segment (Plates 1 and 2). As summarized in Table I, V^2 empties either into the inferior basal vein (50 per cent of specimens), or into the superior basal (44 per cent), or into both (4 per cent). In one instance, it was the middle member of a trifurcating inferior pulmonary vein.

5. The Posterior Basal Segment (B^{10}).—

The bronchial pattern: In contrast to the other basal bronchi of the left lower lobe, B^{10} is the most constant both in its mode of division and in its distribution. It arises alone from the basal trunk, that is, as one of the two stems of the principal bifurcation, in 6 per cent of 110 specimens (Table X). In one-fifth of the lobes (20.9 per cent), it is one of the members of a trifurcation (Plate 5): in three-fifths—the prevailing pattern—it originates with B^2 from the common trunk B^2-^{10} (Plate 2, middle figure).

Before the posterior basal divides into its terminal rami (B^{10a} and B^{10b} —the laterobasal and mediobasal rami) it gives off from one to three *dorsal branches*, BX^* (10). These are present in about 85 per cent of the 110 specimens. The highest of these (or, prevailingly, a single dorsal ramus) supplies the posterior portion of the subsuperior zone (Table XI and Plate 4, C). Its keel arises from 3 to 21 mm. below the keel of B^{10} , at an average distance of 8.7 mm. It thus originates at about the same level as BX^* (9)—the other most constant subsuperior bronchus.

The second type of collateral branch from the stem of B^{10} is the *para-vertebral ramus* (cf. Berg and Boyden, Plate 4). This occurs in a third of 110 specimens (32.8 per cent). This may arise in conjunction with the first or second dorsal ramus, BX^* (10), or separately (12 per cent of 50 specimens). The average distance from the keel of B^{10} is 18 mm.—well above the point where B^{10} divides into its major terminal bronchi.

TABLE X. THE POSTERIOR BASAL BRONCHUS (B^{10})

	PITEL AND BOYDEN (50 SPEC.)	BERG AND BOYDEN (60 SPEC.)	TOTAL (110 SPEC.)
I. Origin of B^{10}			
1. B^{10} arises alone	6%	6.7%	6.4%
2. B^{10} arises in conjunction with B^9	90%	93.3%	91.8%
1) From a trunk dividing into B^9 and B^{10}	56%	66.7%	61.8%
2) Collaterally with B^9 and B^{7+s}	30%	13.3%	20.9%
3) Collaterally with B^8 and B^9	4%	10.0%	7.3%
4) Collaterally with B^{*b}	0%	1.7%	0.9%
5) Collaterally with B^7 and B^9	0%	1.6%	0.9%
3. B^{10} arises collaterally with B^{7+s} and $BX^*(9)$	4%	0.0%	1.8%
II. Terminal rami			
1. B^{10} divides into B^{10a} and B^{10b}	96%	100%	98.2%
2. B^{10a} displaced to B^9	4%	0%	1.8%
III. Collateral branches above terminal rami			
1. One to three dorsal rami, $BX^*(10)$	84%	85%	84.6%
2. A high paravertebral branch	36%*	30%	32.8%
1) Having common origin with $BX^*(10)$	24%		
2) Having separate origin	12%		

*In the 50 specimens of Pitel and Boyden, this 36 per cent of paravertebral rami occurred in specimens already having one or more subsuperiors, $BX^*(10)$. Therefore the main stem of B^{10} was free of large collateral branches in only 16 per cent.

The arterial pattern: In discussing the mode of division of the basal portion of the left pulmonary artery, reference has already been made to the fact that the basal artery bifurcates unexpectedly into A^{10} and A^{7+s} in 46 per cent of fifty specimens (cf. Fig. 2, C; B, Plate 4). In another 42 per cent, it divides into an expected A^{7+s} and A^{9+10} . In the remaining 12 per cent, it is either one stem of a trifurcation (Plate 4, #7) or associated irregularly with A^7 (8 per cent of fifty specimens).

TABLE XI. DISTRIBUTION OF $BX^*(10)$

	PITEL AND BOYDEN (50 SPEC.)	BERG AND BOYDEN (60 SPEC.)	TOTAL (110 SPEC.)
I. Sector			
1. Wholly posterior	12%	36.7%	25.5%
2. Posterior and posterolateral	38%	25.0%	30.9%
3. Posterolateral only	22%	15.0%	18.2%
4. Posterolateral and lateral	6%	1.7%	3.6%
5. Paravertebral and posterior	2%	5.0%	3.6%
6. Paravertebral, posterior, and postero-lateral	4%	1.7%	2.7%
	84%	85%	84.5%
II. Angle made with anterior surface of lobe			
1. 75-100 degrees (posterior)	72%	62%	66.3%
2. 45-50 degrees (posterolateral)	12%	23%	18.2%
	84%	85%	84.5%*

*Note that the posterolateral sector of the subsuperior zone is supplied by $BX^*(10)$ in nearly two-thirds of the specimen having a subsuperior of this type. (Add items 2, 3, 4, and 6.)

The venous pattern: It will be recalled that the posterior basal segment is separated from the lateral basal by V^9 (Plate 1). Otherwise the principal drainage of the posterior basal segment is mediated by V^{10} . This has two principal tributaries—a segmental vein (V^{10a}) and an intersegmental vein (V^{10b}). In 92 per cent of fifty specimens, V^{10} empties into the inferior basal vein (Plate 1). In the remaining 8 per cent it is split into two veins, one draining into the inferior basal, the other into the superior basal vein (Table I).

6. The Subsuperior Zone.—

The bronchial supply: This zone receives its name from a dorsal bronchus (B^*)—the second dorsal of Aeby—which arises either from the basal trunk of the lobe (9 per cent of 110 specimens) or from the common stem of $B^9 +^{10}$ (18 per cent). This bronchus differs from the corresponding bronchus of the right lower lobe in two major respects: first, in its less frequent occurrence—27 per cent as against 61 per cent—and, second, in its distribution—that of the left (Table XII) supplying the posterolateral and often the lateral (as well as the posterior) sector of the zone which is interpolated between superior and basal segments, that of the right supplying primarily the posterior sector. For these reasons, Berg and Boyden concluded that any dorsal bronchus which supplied the territory of the left B^* should be considered as an accessory subsuperior bronchus (BX^*)—namely the high dorsal branch of B^9 [BX^* (9)] and the high dorsal branch of B^{10} [BX^* (10)]. Indeed, one or both of these (third dorsal level of Aeby) supply the subsuperior zone exclusively in 72.7 per cent of 110 specimens (Table XII). Their occurrence and distribution are summarized in Tables IX, XI, XII, XIII, and XIV, and their origin on the bronchial tree is illustrated in Fig. 1.

TABLE XII. POSITION AND ORIENTATION OF SUBSUPERIORS PROPER (B^*)

	PITEL AND BOYDEN (50 SPEC.)	BERG AND BOYDEN (60 SPEC.)	TOTAL (110 SPEC.)
I. Level on bronchial tree			
1. Above origin of $B^7 + ^8$	14%	5%	9.1%
2. From common stem of $B^9 + ^{10}$	12%	24%	18.2%
	26%	29%	27.3%
II. Position of orifice on circumference			
1. Posterior (or slightly posterolateral)	14%	12%	12.7%
2. Posterolateral	6%	12%	9.1%
3. Lateral (or slightly posterolateral)	2%	5%	3.6%
4. Medial	4%	0%	1.8%
III. Angle of subsuperior bronchus with anterior surface			
1. 40-45 degrees (i.e., posterolateral)	14%	23%	18.2%
2. 20-30 degrees (i.e., almost lateral)	8%	3%	5.4%
3. 80-100 degrees (i.e., posterior)	4%	3%	3.6%
IV. Distribution on surface			
1. Posterolateral and lateral	20%	14%	16.4%
2. Posterior, posterolateral, and lateral	0%	10%	5.4%
3. Posterolateral only	2%	3%	2.7%
4. Posterior and posterolateral	0%	2%	0.9%
5. Paravertebral only	4%	0%	1.8%
			27.2%*

*Note that the posterolateral sector of the subsuperior zone is supplied by B^* in 94% of the specimens having a subsuperior bronchus. (Add items 1, 2, 3, and 4.)

TABLE XIII OCCURRENCE OF SUBSUPERIOR BRONCHI (B^* AND BX^*)

	PITEL AND BOYDEN (50 SPEC)	BERG AND BOYDEN (60 SPEC)	TOTAL (110 SPEC)
1 Frequency of occurrence according to levels			
B^* only (level d_2)*	4%	6.6%	5.5%
BX^* only (level d_3)†	74%	71.7%	72.7%
B^* plus BX^* (both levels)	22%	21.7%	21.8%
2 Number of subsuperiors per specimen			
One subsuperior	18%	21.7%	20.0%
Two subsuperiors	32%	61.7%	48.2%
Three subsuperiors	26%	16.6%	20.9%
Four subsuperiors	24%	0.0%	10.9%
3 Frequency of occurrence of various types of subsuperiors			
B^*	26%	28.3%	27.3%
BX^* (9)	80%	66.7%	72.7%
BX^* (10)	84%	85.0%	84.5%

*Subsuperiors proper, arising below B^* and above the keel which separates B^* and B^{10}

†Accessory subsuperiors, arising below the keel which separates B^* and B^{10} either from the upper portion of the trunk of B^{10} [BX^* (10)] or the upper portion of the trunk of B^* [BX^* (9)], or from both

Mention has been made of the frequent extension of the subsuperior bronchi into the anterolateral sector of the zone. In other words, B^* , BX^* (9), and occasionally BX^* (10) invade the territory of the lateral ramus of the anterior basal bronchus (B^a). In our fifty specimens (footnote, Table VII), B^a was supplemented or replaced by X^a branches of the subsuperior bronchi

TABLE XIV DETAILED ANALYSIS OF NUMBERS OF SUBSUPERIORS PER SPECIMEN

	PITEL AND BOYDEN (50 SPEC)	BERG AND BOYDEN (60 SPEC)	TOTAL (110 SPEC)
1 One subsuperior			
Level d_1 (B^*)	4%	6.7%	5.45%
Level d_2			
BX^* (9)	12%	6.7%	9.1%
BX^* (10)	2%	8.3%	5.45%
	18%	21.7%	20.00%
2 Two subsuperiors			
Both levels			
B^* and BX^* (9)	0%	1.7%	0.9%
B^* and BX^* (10)	4%	11.7%	8.2%
Level d_2			
BX^* (9) and BX^* (10)	26%	43.3%	35.5%
Two BX^* (10)	2%	5.0%	3.6%
	32%	61.7%	48.2%
3 Three subsuperiors			
Both levels			
Two B^* , one BX^* (10)	2%	1.6%	1.8%
One B^* , one BX^* (9), one BX^* (10)	8%	6.7%	7.3%
One BX^* (9), two BX^* (10)	12%	8.3%	10.0%
Three BX^* (10)	4%	0%	1.8%
	26%	16.6%	20.9%
4 Four subsuperiors			
Both levels			
One B^* , three BX^* (10)	2%	0%	0.9%
One B^* , one BX^* (9), two BX^* (10)	6%	0%	2.7%
Level d_2			
One BX^* (9), three BX^* (10)	16%	0%	7.3%
	24%	0%	10.9%

in one-third of the lobes (35.4 per cent). Such variations are illustrated in Plates 4, B, and 5.

Origin of the subsuperior arteries: The arteries that accompany the subsuperior proper (A^*) arise at different levels on the trunk and branches of the inferior pulmonary artery. In 4 per cent of fifty lobes they arise from the basal artery, in 6 per cent from the common trunk of A^{7-9} , in 8 per cent from the common trunk of A^{9+10} (Plate 3), in 6 per cent from A^{10} , and in one instance (2 per cent) from A^9 .

The arteries accompanying $BX^*(9)$ arise prevailing from A^9 (56 per cent: Plate 4, B), next in frequency from A^{10a} (10 per cent), then less frequently from the trunks of A^{7-9} or A^{7-9} (8 per cent), A^{9+10} or A^{9+10a} (6 per cent), and A^8a (4 per cent). In two specimens there were two arteries to a bronchus—from adjacent sides of A^9 and A^{10} .

The arteries accompanying $BX^*(10)$ arise prevailing from A^{10} (42 per cent: Plate 4, B), then with about equal frequency from A^9 (14 per cent), A^{10a} (12 per cent), A^{10b} (12 per cent), and infrequently from the trunks of A^{7-10} (4 per cent) or A^{7-9} (2 per cent). In one specimen, there were two arteries to one bronchus, from adjacent sides of A^9 and A^{10} .

The veins of the subsuperior zone: Since B^* is directed primarily to a posterior lateral sector of the zone (Plate 1) it is to be expected that V^* , the vein lying on the clockwise side of B^* , should pass between B^{7+8} and B^9 to gain the superior basal vein or one of its tributaries (V^8a). Such is the case in ten of the thirteen specimens in which it occurs (cf. Plate 2, right figure). In the remaining three specimens, V^* drains into V^6 (see VX^8a branch of V^* , Plate 5) or into the common basal vein (Plate 3).

A similar course is followed by $VX^*(9)$ —the vein which lies on the clockwise side of $BX^*(9)$. In thirty-two of the thirty-seven specimens in which it occurs, $VX^*(9)$ runs between B^8 and B^9 to enter V^8a (cf. Plate 2, right figure). In the remaining five specimens, it courses between B^9 and B^{10} to enter V^9 . In three of the five, however, it first joins V^* or $VX^*(10)$ before entering V^9 .

The third subsuperior vein (Plate 1) is $VX^*(10)$. Since in one-half the specimens there are two or more subsuperior bronchi of this type (Table XIV), we shall restrict the description to the vein accompanying the highest $VX^*(10)$, if more than one is present, for the lower ones are less significant and drain into V^{10} . The principal $VX^*(10)$ lies on the clockwise side of $BX^*(10)$. Commonly, it passes through the crotch between B^9 and B^{10} (Plate 1). There, in about one-half the thirty-four specimens in which it occurs, it empties directly into V^9 , the most centrally placed of the basal veins. In most of the remaining specimens it joins some other centrally placed vein—even forming one of its own in conjunction with $VX^*(9)$ or V^* (Plate 4, A and B). In five cases, however, it is displaced laterally to enter V^8a between B^8 and B^9 .

SUMMARY OF STRIKING DIFFERENCES BETWEEN LEFT AND RIGHT LOWER LOBES

The key to the differences of pattern in left and right lower lobes is to be found in the position of the medial basal bronchus (B^7). In the right lung it

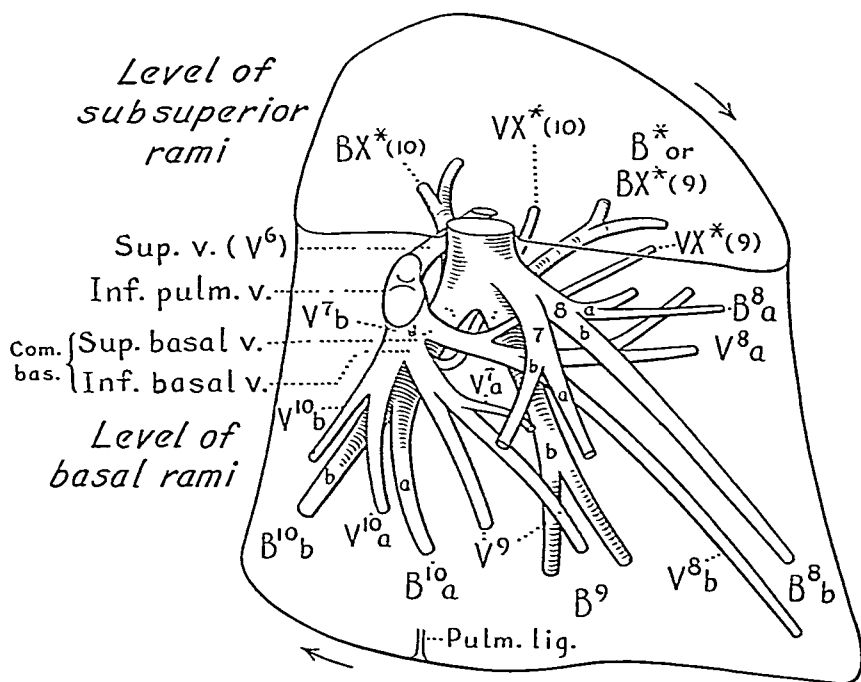
is medially placed and therefore distributes to both anterior and paravertebral surfaces. Because of this, the bronchus embraces the inferior pulmonary vein in one-fourth of the lobes. In another one-fifth its two rami arise separately—one on either side of the vein (Ferry and Boyden, 1951). In the left lung the medial basal bronchus arises in common with B^s , the lateral basal bronchus. Accordingly, B^r never distributes to the paravertebral surface but always remains on the lateral side of the pulmonary ligament. This holds true even in the 7 per cent of specimens in which B^r arises independently from the antero-medial portion of the basal stem. Correspondingly it never “tangles” with the inferior pulmonary vein. Indeed, the only occasion in which the left pulmonary vein and its large branches pass superficial to B^r is when the latter arises anomalously from B^{10} (Fig. 3).

Because of this fundamental difference in the two sides, the mode of entrance into the two lobes (for purposes of exposing the large veins and deeper bronchi) is quite different. On the right side a cleavage plane marked by $V^s b$ is entered and the medial basal segment is reflected medially. On the left, one proceeds through the pulmonary ligament to an underlying cleavage plane formed by $V^r b$, and then reflects the medial basal segment laterally.

Thus exposed, the pattern of the great veins is found to be essentially similar—namely, the inferior pulmonary is formed by the confluence of a superior vein (V^s) and a common basal vein, the latter in turn is formed by the union of superior and inferior basal veins. However, the composition of the basal veins differs somewhat in the two lobes. On the left side, V^s commonly enters the inferior basal vein (Plate 1) instead of the superior basal, as on the right side. Furthermore the left inferior pulmonary is much less variable. In 14 per cent, the right pulmonary is formed by union of three or four major veins receiving substantial tributaries from the middle lobe and even from the right upper lobe (Table III, Ferry and Boyden). Such an arrangement has never been encountered by us in the left lower lobe.

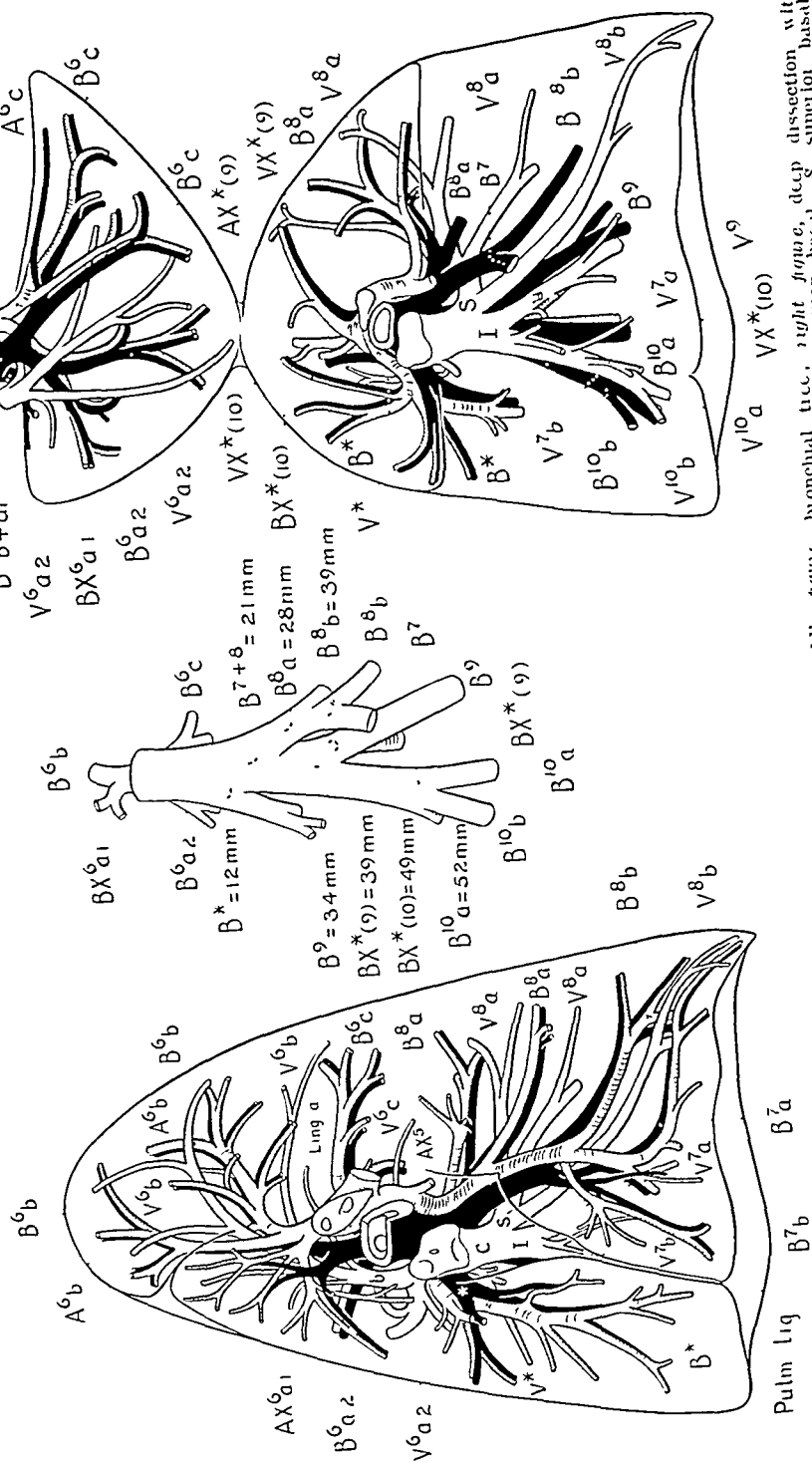
In the left superior segment, due to the greater development of the medial ramus (B^{sa}) the superior vein usually receives three major tributaries (V^{sa} , b , and c) instead of the two on the right (V^{sb} and c). Correspondingly, multiple arteries to the left superior segment are more common, occurring in 36 per cent of specimens, as against 20 per cent for the right superior segment. Furthermore, they arise from the interlobar portion of the pulmonary artery above the level of the lingular arteries—a point of great importance in lobectomy—whereas on the right, they occur both above and below the middle lobe arteries. Curiously enough, the left superior segmental bronchus (B^r) is “conservative” in its origin. Only one instance (in 110 specimens) was found in which it arose as two separate stems (Plate 4, #7). In this case the lower stem (B^{ra}) arose from the medial side of the basal trunk. In the right lung, two separate origins of B^s were encountered in 6 per cent of 100 specimens. In these cases the lower stem tends to originate on the lateral side and to involve ramus B^{sc} .

The subsuperior bronchi (B^s) are fewer in number on the left side—27 per cent as against 61 per cent on the right. Furthermore, they are oriented in



Scheme showing common arrangement
of veins in basal segments
(Inf. pulm. v. retracted medially)

Plate 1—Diagram of truncated left lower lobe. The superior segment has been removed to show subsuperior rami.



Pulm liq β^7_a β^7_b

Plate 2—Specimen #44 Left *frange*, dissected anterior surface. middle *frange*, bronchial tree, right *frange*, deep dissection with superior segment tipped back on a hinge. Bronchi in black, arteries in red, veins in blue color. C, common basal, S, superior basal, I, inferior basal vein

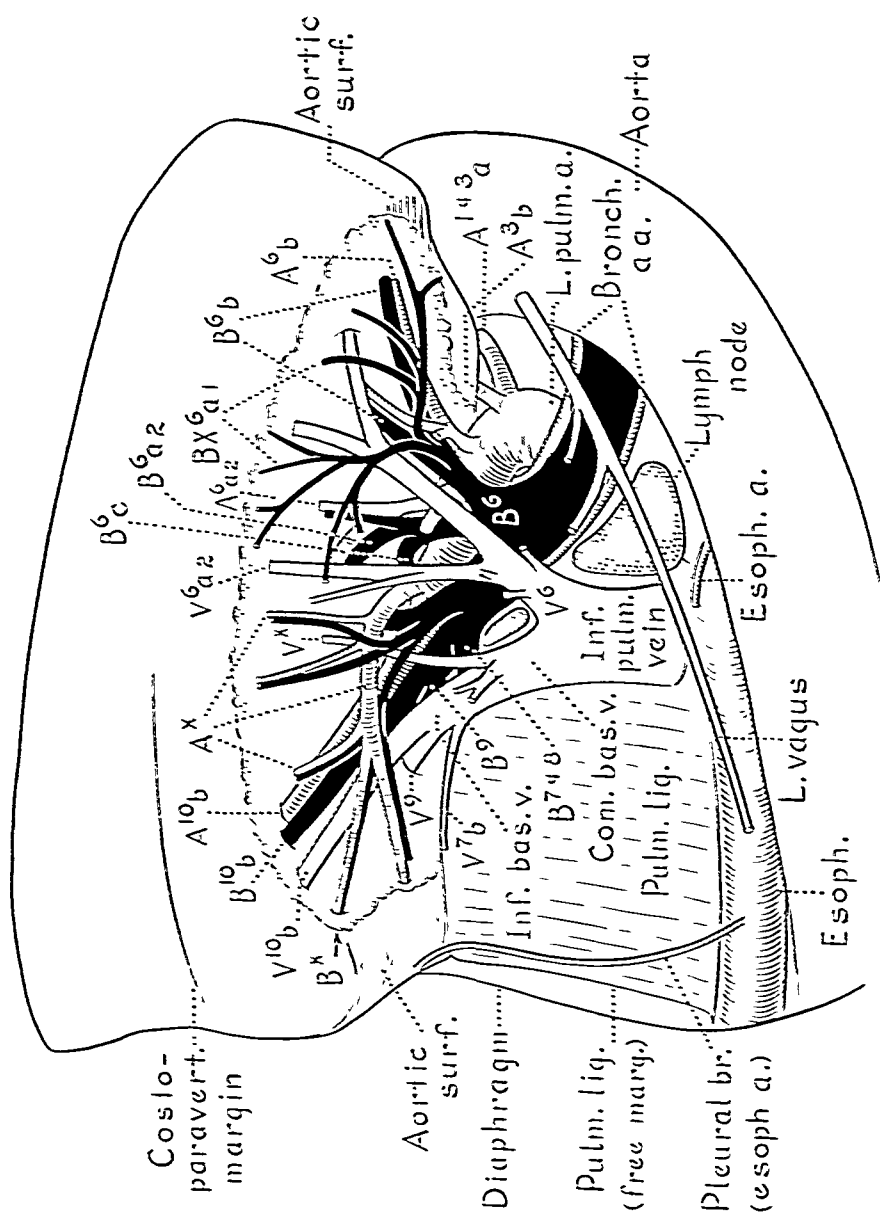
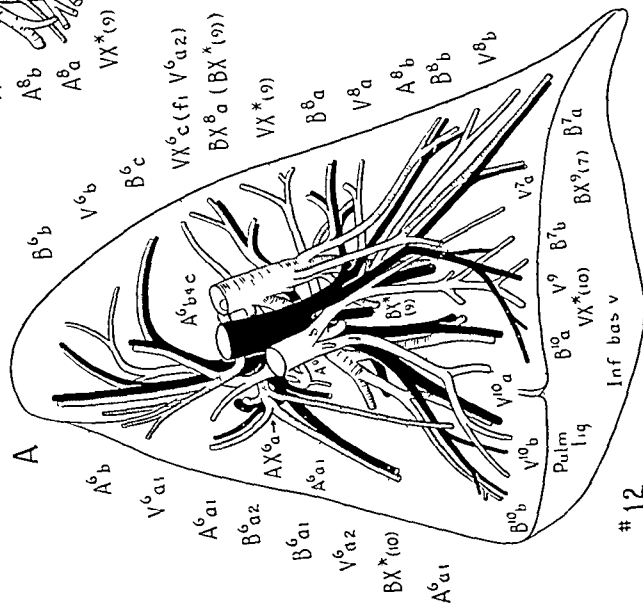
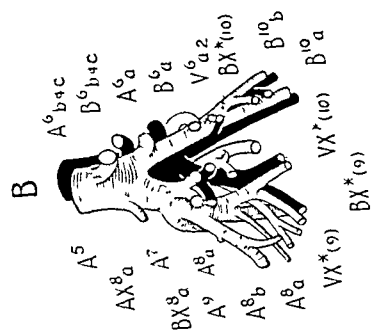
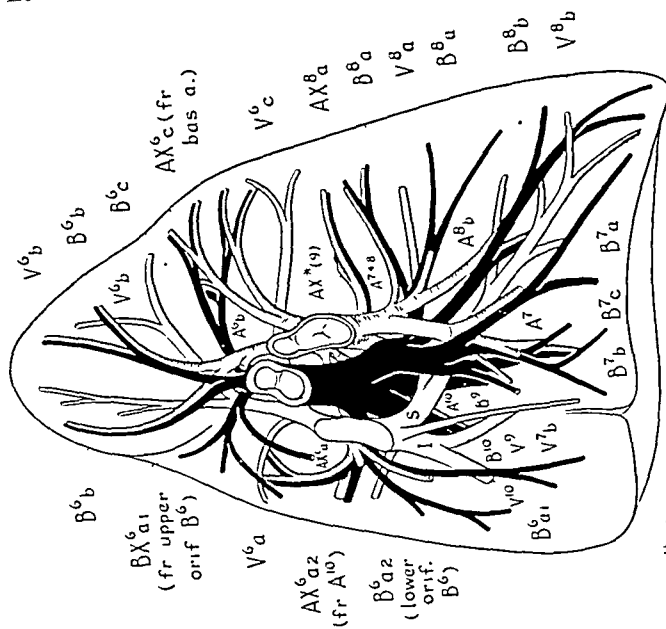


Plate 3.- Specimen #44. Left lower lobe elevated and drawn in situ. Small veins on stem of V^6 and common basal vein are bronchial veins.



12



7

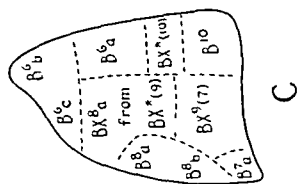


Plate 4—A, B, and C, three views of Specimen #12. Specimen #7 illustrates double origin of bronchi of superior segment.

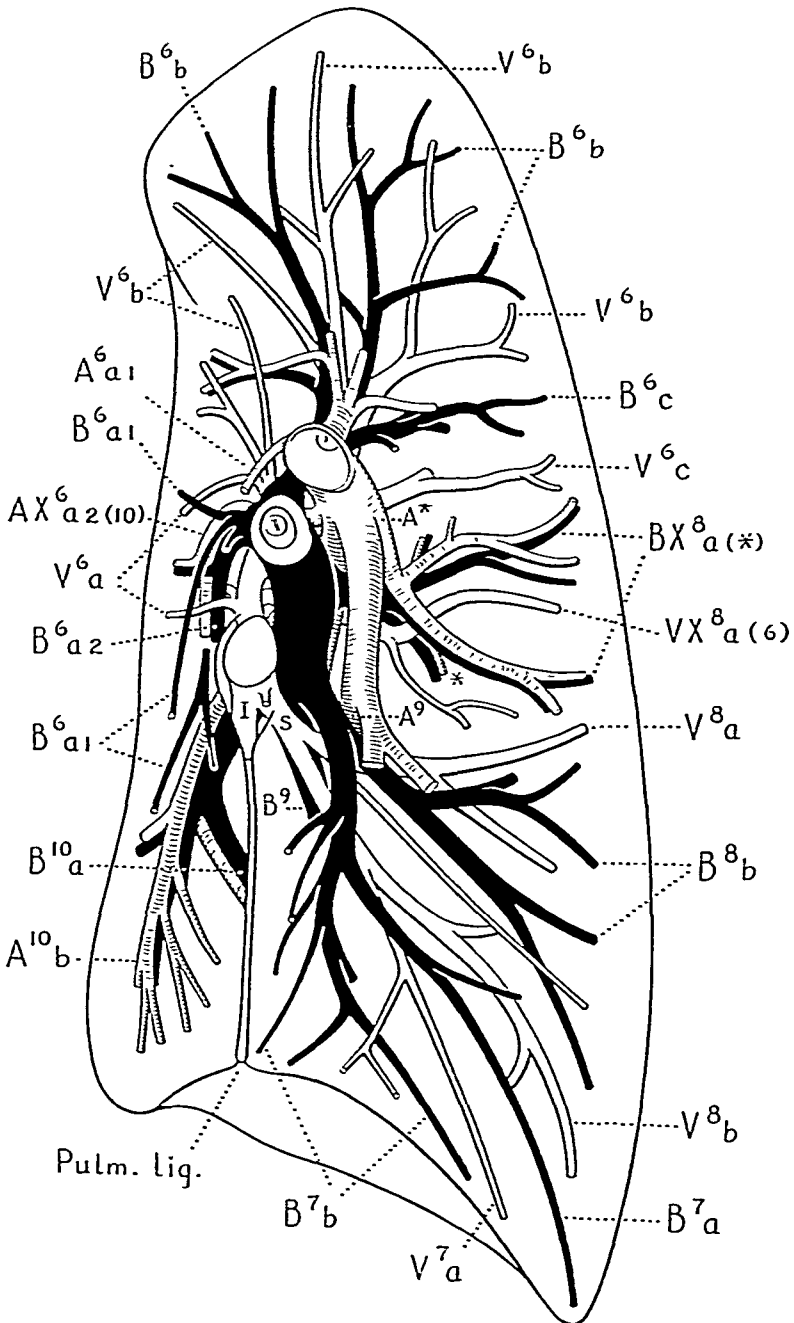


Plate 5.—Specimen 46. Dissection of anterior surface.

a posterolateral instead of a posterior direction. Therefore, in the absence of B^* on the left, the posterior lateral portion of the zone is supplied by the highest branch of B^9 (the B^9a ramus of the right side)—namely $BX^*(9)$. One of the most characteristic features of the left subsuperior zone is its invasion of the anterior surface of the anterior basal segment. This occurs in over one-third of the lobes.

Turning to the basal segments, the anterior basal is the most variable of the left basal bronchi, whereas on the right it is the most constant. One or the other of its two rami is missing in 17 per cent of 110 specimens; B^9a is supplemented or wholly replaced by subsuperior bronchi in 35 per cent; B^9b fails to reach the diaphragmatic surface in 19 per cent, finally, the common stem of B^7 and B^8 divides unevenly into B^9a and B^{7+8b} in 20 per cent. In addition, B^9 (the lateral basal bronchus) is missing on the left side in 11 per cent of 110 specimens, being usually displaced onto some portion of the B^{7+8} stem. As a result of these related variations there is a profound change in the arterial pattern of the left side. Whereas in the right lung the basal portion of the inferior pulmonary artery divides into A^9 and A^{10} in nearly one half of the lobes (44 per cent), the left basal artery divides unevenly into A^{10} and A^{7+9} in 46 per cent of specimens. In consequence of this unexpected grouping of segmental arteries, A^9 arises anomalously from the deep side of A^{10} , A^8 , A^9a , or A^9b in 22 per cent of lobes. In addition, the pattern of the anteromedial basal arteries conforms to the bronchial pattern in less than one-third of the specimens. This constitutes a considerable hazard to the individual resections of the first three basal segments.

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Announcement

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The 34th annual meeting of the American Association for Thoracic Surgery will be held May 3, 4, and 5, 1954, in Montreal, Que., Canada. Headquarters will be at the Sheraton-Mount Royal Hotel.

Requests for Hotel Reservations

These should be mailed *directly* to the Reservation Manager, Sheraton-Mount Royal Hotel, Montreal, Que., Canada. Please mention this Association, type of accommodation desired, date, and approximate hour of arrival. If accommodations are desired elsewhere, please communicate directly with hotel of your choice.

Thoracic Surgical Forum

After due consideration, the Council has decided to try an experiment by assigning one morning session to a "Thoracic Surgical Forum" for the presentation of short papers on current thoracic research, anatomy, modified surgical techniques, etc. Papers at this session will be limited sharply to ten minutes (including the showing of lantern slides or other illustrative material) with three minutes as the maximum discussion of each paper.

These papers will be published together in one issue of THE JOURNAL OF THORACIC SURGERY. Maximum length: 3,000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts for Papers

Abstracts for the presentation of papers at the 1954 meeting, including papers before the Forum, must be received on or before January 1, 1954, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Forum" or "For Regular Program."

Five, repeat five, copies of each abstract should be sent to the Secretary of the Association, Dr. Paul C. Samson, 2938 McClure St., Oakland 9, Calif. They should not be sent to the Editor.

The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Jan. 1, 1954, to be considered for action in Montreal. Applications received beyond this deadline will be deferred for consideration until 1955.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the sponsoring statement on the application form, the sponsors *must* submit a separate letter concerning the applicant direct to Dr. Lyman H. Brewer, III, Chairman of the Membership Committee, 2010 Wilshire Blvd., Los Angeles, Calif. Completed application forms should likewise be sent to Dr. Brewer. These regulations are at the direction of the Council and were made effective in 1952 at Dallas.

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